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CONTENTS

SPECIAL FEATURES

SPECIAL EVENTS

NOTES AND NEWS

THE AUTOMATIC RECORDING AND ANALYSIS OF MAGNETIC FIELDS

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Abstract

The system described was devised to increase the rate at which equipment for Royal Navy ships can be magnetically evaluated. A modified data logger samples the output of up to nine magnetometers simultaneously and records them sequentially on punched tape for subsequent automatic processing. Sampling is repetitive, controlled by an induction measuring system which also gives a continuous display of the position of an object being ranged.

Introduction

Ever since the introduction of the magnetic mine into naval warfare it has been important to know the magnetic properties of ships. During and after the last war a great deal of work was done in the field of "degaussing" and a number of magnetic "ranges" were established to enable the complete magnetic fields of vessels to be measured.

In a typical sea range a row of magnetic detectors is laid at regular intervals in a straight line on the sea bed and connected electrically to suitable indicating and recording instruments. If a ship is made to pass over the range, or stationed over it, according to the nature of the detectors, it is possible to measure the magnetic disturbance produced. Unfortunately, this is a slow and expensive procedure and only provides information on the combined magnetic properties of the ship and its contents.

With a steel-hulled vessel the hull itself will make a large contribution to the total field of the ship and a sea range is the only practical means of measuring its overall magnetic condition. However, in the case of a vessel with a non-magnetic hull, such as a minesweeper, the total field is due only to the machinery and equipment, which need not be mounted in the hull for their individual magnetic properties to be measured. Also, in the absence of the blanketing effect of a magnetic hull, the contents assume a greater significance and their individual effects need to be measured to a higher degree of accuracy than before.

For these reasons a "land range" was constructed in the mid-1960s for the Ship Department of the Ministry of Defence (Navy) in Ditton Park, Slough, to facilitate the precise measurement of the magnetic fields associated with the equipment and fittings of naval vessels for which the Director General of Ships is responsible.

This Range, which has now been operating for several years, forms part of the Electrical Division of the Amiralty Engineering Laboratory.

General Description of the Range

Figure 1 (a) gives a general view of the Ditton Park Range. It consists basically of a railway, aligned with the magnetic meridian and about 150 ft. in length, along which objects can be towed on a trolley past a group of magnetometers. All the materials used in the construction of the working space of the Range are non-magnetic.

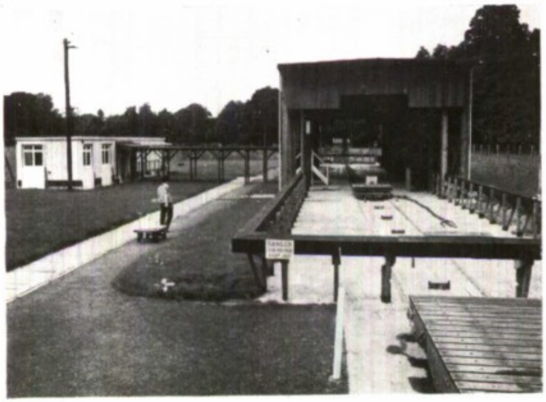

FIG. 1 (a). General view of the Ditton Park Range.

Up to nine magnetometers may be used, each one being normally supported in a vertical glass-fibre tube sunk into the ground. These tubes are set in a row, 4 ft. apart, at right angles to the track and half-way along it (Figure 2). The magnetometers are located by rods attached to dividing heads at the tops of the tubes. By raising or lowering the rods measurements may be made at depths of up to 30 ft. to simulate the depth of water of a sea range.

FIG. 1. (b). Electrical generator being loaded on to 10-ton trolley for ranging.

At the northern end of the track a variable-speed electric winch is installed. This drives a system of pulleys and wire ropes that is capable of towing objects weighing up to 10 tons at a speed of 2 ft. per second on the larger of the two trolleys available (Figure 1 (b)). For smaller objects another trolley of 1 ton capacity, with a turntable top, is provided.

FIG. 2. Tops of magnetometer support tubes.

The central section of the Range is protected by a wooden canopy which also supports a set of large electrical field coils. One, known as the Z-coil, is mounted horizontally 3 ft. above ground level so that the centre of the average sized object, when mounted on a trolley, lies in the same plane. Another group of coils, known collectively as the X-coil, is arranged in parallel vertical planes attached to the supports of the canopy. (The relative dispositions of the track, the magnetometers and the coils are shown in Figure 3).

The field coils are connected by cables to an electronic power unit which provides two variable D.C. supplies of up to about 7 amperes at 70 volts. By adjusting the currents in the two coils the field at the centre of the range can be modified, reduced to zero or oscillated in the vertical plane in order to simulate the effect of a ship pitching or rolling.

The measuring and recording equipment is installed in an office building located some 50 ft. to the west of the centre of the range. The instrument room is fitted with observation windows looking out over the range and is equipped with telephones and loudspeakers to facilitate control of operations. Air conditioning is provided in the instrument room to remove heat generated by the equipment and to ensure the accuracy of the measurements.

which affect the site as a whole, a tenth magnetometer is located some distance from the centre of the Range. This is connected to a modified oerstedmeter in the instrument room which provides simultaneous outputs of the N-S, E-W and Vertical fields detected. These signals are then fed through compensating windings on the corresponding axes of the nine "working" magnetometers in the correct sense to neutralize their noise outputs.

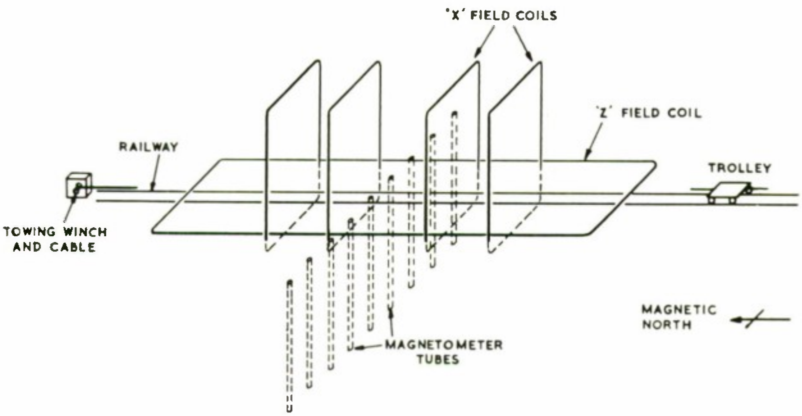

FIG. 3. Perspective diagram of the Range.

Fields and their Measurement

The Magnetometers

The magnetometers are 3-axis devices of the second-harmonic flux gate type contained in plastic cylindrical shells 3·5 in. in diameter and 10 in. long (Fig. 4). Each unit is connected by a multi-core flexible cable to an associated electronic cabinet in the instrument room known as an oerstedmeter.

Each oerstedmeter can be switched to measure the N-S, E-W or Vertical component of the magnetic field and display the measurement on a centre-zero meter. Controls are provided for adjusting the sensitivity and also for backing-off the reading electrically to enable small changes of field strength to be measured in the presence of large standing fields.

On the maximum sensitivity setting the oerstedmeters read $\pm$ 1 milli-oersted for full-scale deflection. Each division of the meter, calibrated 100 - 0 - 100, therefore represents 10 micro-oersteds, or 1 gamma in the units normally employed in degaussing terminology. An electrical output is also available from each oerstedmeter, full scale output corresponding to $\pm$ 1·5 volts d.c.

To enable measurements to be made consistently at maximum sensitivity, in the presence of moment - to - moment magnetic disturbances

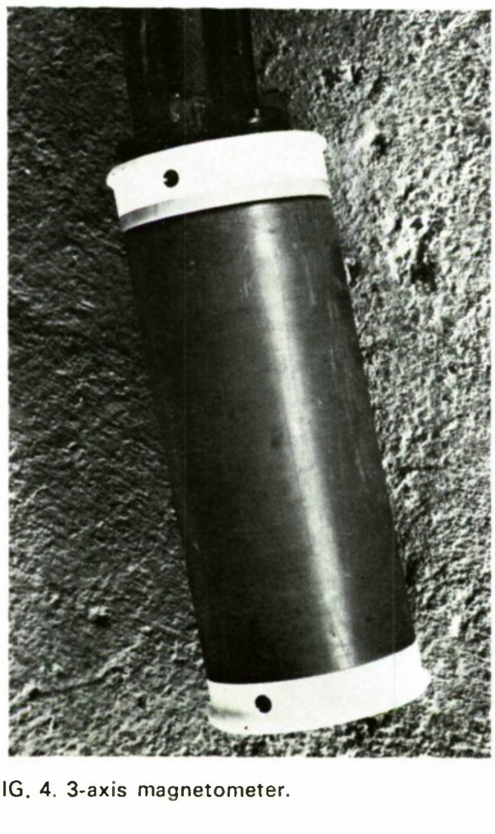

FIG. 4. 3-axis magnetometer.

Graphical Recording

When the Range was originally commissioned it was equipped with several large servo-operated chart recorders that provided nine simultaneous channels—one for each oerstedmeter. Thus at the end of a run the general distribution of the field of the object being measured could be assessed visually from the relative amplitudes of the various curves, while the peak value of the field could be determined and measured against the divisions of the chart paper. Usually it is required to find the peak value of the field relative to a reference point on the object. This was facilitated in the original recording system by the provision of micro-switches along the track, actuated by the passage of the trolley, which superimposed "marker pulses" on the record charts. A double pulse was generated at the centre of the Range and the position of a peak signal could therefore be obtained by interpolation against the ruling of the chart paper.

Types of Field

The Range is concerned with four types of magnetic field; these are:—

(i) Permanent fields (the P component) due to the permanent magnetism of a ferromagnetic object,

(ii) Induced fields (the I component) due to the magnetism induced into an object, having a permeability other than unity, by the earth's field,

(iii) Stray fields, created by the passage of current through the windings of electrical equipment, and

(iv) Eddy-current fields, due to the angular rotation of electrically conductive objects in the earth's field.

Separation of Permanent and Induced Fields

When an object containing magnetic materials is passed along the Range in the earth's field the magnetometers will detect a combination of permanent and induced fields. If a second run is then made, with the earth's field neutralized with the field coils, the measurements obtained will be of the permanent field of the object alone.

In order to obtain a record of the induced field, the P record from each magnetometer must be subtracted from the P + I record. This was originally done manually from the chart recordings and proved to be very tedious when several magnetometers were being used for measurements along all three axes.

Stray and Eddy-current Fields

Stray field measurements are carried out in a simiar manner by taking two sets of measurements of the object, one with it unenergised and one with it energised, and then obtaining the difference.

Eddy-current measurements are carried out by setting the object stationary at the centre of the Range with the oerstedmeters backed-off and the magnetometers compensated for the direct influence of the X and Z coils. The coil currents are then slowly modulated by a suitable amount. If there are no significant eddy currents in the object there will be no appreciable outputs from the oerstedmeters. On the other hand, if there are significant eddy currents the oerstedmeters will show a cyclic output at modulation frequency that is proportional to the magnitude of the eddy current effect.

Methods of Recording and Analysis

Need for an Automatic System

After the Range had been in use for some months it became apparent that a considerable proportion of the time required to complete a job was occupied in analysing the recordings. Typically, it was found that a job which took 52 working hours of the Range's time required some 15 hours of analysis, although the total recording time, including trial runs, was only 45 minutes.

It was therefore concluded that a significant improvement in output could be achieved if the analytical work could be partly or wholly automated and an investigation into possible means of achieving this was carried out at A.E.L.

For the purposes of this investigation it was assumed that economic considerations would dictate the retention of as much of the existing instrumentation as possible and that elaborate equipment costing more than the original installation could not be justified.

From the outset it was clear that aids to the analysis of the measurements could be divided into two main categories: those which would operate on the existing analogue form of recording and those employing digital methods. Two systems of each type were therefore considered in some detail and preliminary cost estimates obtained. In order to simplify the comparison

attention was concentrated on the process of P and I separation, as it was thought that any equipment capable of reducing the time spent on this operation would probably be suitable for carrying out the other analytical processes.

Analogue Methods

The simplest type of semi-automatic analogue processing system investigated was a modified form of commercial chart reader. This would have enabled an operator to position two cursors, one on a P + I curve and one on a P curve, the two records being superimposed on a rear-illuminated translucent screen. The equipment would develop voltages proportional, respectively, to the P + I, P and X (track position) co-ordinates. The P signal would be subtracted from the P + I signal in a differential amplifier and the output (I) applied to the 'Y' axis of an X-Y plotter. The X signal would be applied to the 'X' axis of the plotter and the pen would therefore draw out the required induced field curve.

The other analogue system considered was an automatic version of the chart reader arrangement with the manually operated cursors replaced by two separate curve-following devices. This would have had the advantages over the manual system of speed of operation, reduction of operating errors and the ability to draw a continuous curve instead of a series of dis-connected points.

Digital Methods

Both the analogue systems considered took the chart recordings as their source of information and their overall accuracy would therefore have been limited by the performance of the recorders. In order to avoid the accumulation of errors it is obviously preferable to operate directly on the signal voltages developed by the oerstedmeters. However, in order to separate a P + I run from a P run at least one of the runs must be recorded, since the two sets of information are not generated at the same time. Attention was therefore given to alternative methods of storing and processing the measurements, particularly digital methods. Two systems were investigated; one employing punched paper tape as the storage medium, with a small electronic desk calculator for subsequent processing, and the other using magnetic core storage with fast computer-type processing. In both cases automatic print-out of the results in tabular form was envisaged.

With any digital method, of course, the measurements are made at discrete intervals instead of continuously and a decision had to be taken as to how often the outputs of the oerstedmeters should be sampled in order to be certain that the peak values would not be missed. Assuming that measurements are taken to three significant figures the maximum rate of recording that could be achieved at the time with a good digital voltmeter linked to a high speed tape punch was just over eight measurements a second (including sign). Examination of typical analogue recordings showed that measurements would have to be taken at intervals of the order of six inches along the track in order to ensure errors no greater than 2% with the magnetometers at a depth of five feet. This indicated that it would be necessary to run the trolley at about five inches a second if all nine magnetometers were being used. If, as is more usual, only five magnetometers were recorded simultaneously, then the speed of the trolley could be increased to nine inches a second. It should be noted that with small objects whose fields are of limited extent it is desirable to measure at smaller intervals. Fortunately only three or five magnetometers are used for such objects and the number of measurements to be recorded each second therefore remains substantially independent of magnetometer depth.

In order to obtain intelligible results it is desirable that the outputs from all the magnetometers should be recorded simultaneously for a given position of the trolley. However, to achieve this with only one measuring channel the trolley would have to be run at an extremely low speed if a conventional sequential scanning arrangement were used. The only practicable alternative is to sample the oerstedmeter outputs simultaneously, store them and then feed them in sequence to the recording equipment while the trolley is moving on to the next measuring point.

The alternative digital system considered was an electronic data storage and analysis instrument developed originally for nucleonic sampling. This would have been capable of scanning up to eight magnetometers, digitizing their outputs and holding the results in a core store of large capacity. As the sampling was performed electronically at micro-second intervals no "sample-and-store" scanning arrangement would have been needed. Unfortunately, this system had the disadvantage that only positive measurements could be recorded directly.

Negative quantities could only be dealt with by feeding a large fixed number into the stores before each run and then subtracting it from the final results by some other means, such as a desk calculator.

Comparison of Alternative Methods

In forming a comparison between the four systems discussed above three main criteria were borne in mind. These were:

(i) Speed of recording and processing;

(ii) Cost and,

(iii) Accuracy.

Little can be said about accuracy, since it is difficult to specify an overall figure for the performance of the Range. However, it was considered that the recording and processing of the outputs of the oerstedmeters should not introduce errors of more than 5%* and, preferably, not more than 3%.

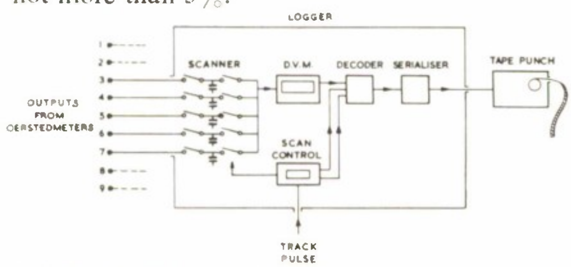

FIG. 5 (a). Block of diagram of logger.

With regard to the analogue systems, it was felt that the errors introduced by successive graphical operations outweighed the advantages of lower cost compared with the digital systems and it was therefore decided not to proceed with either of the former.

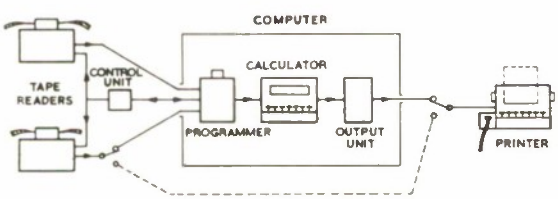

FIG. 5 (b). Block diagram of processor.

Of the two digital systems, recording on punched paper tape with subsequent analysis by means of a simple electronic desk calculator equipped with print-out seemed to have the following advantages over the high-speed computer-type system:

(a) Moderate cost.

(b) The ability to handle both positive and negative outputs from all nine magnetometers, rather than eight.

(c) The ability to process the measurements completely "off-line," so that fresh measurements could be recorded while the last were being analysed.

(d) The processor could be used independently as a desk calculator when not being used for routine analysis.

For these reasons it was decided to proceed with the acquisition of a punched tape system of the kind outlined.

Description of Digital Recorder and Processor

The Logger

Fig. 5a is a block diagram of the recording system now installed at the Range. It consists basically of a commercial data logger modified by the addition of an input scanning circuit which is arranged to sample the oerstedmeter outputs simultaneously at any given instant and then to feed them, in sequence, to a digital voltmeter for measurement of their signs and amplitudes. The output of the voltmeter is passed through a coding device to a serialiser which controls a high-speed tape punch, Fig. 6(a).

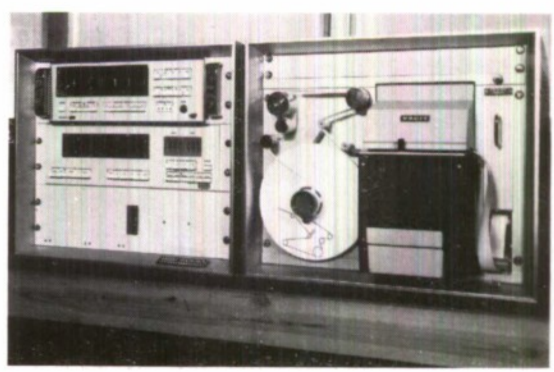

FIG. 6 (a). The logger and tape punch.

The scanning circuit consists of a bank of low-leakage capacitors each connected to the junction of a pair of reed switches. One side of each pair of switches is connected to the input terminal of one channel of the logger and the other side to one of the oerstedmeters. In operation, the input switches, *i.e.* those between the oerstedmeters and the capacitors, are controlled by trigger pulses generated by the movement of the trolley along the track. At each

* Expressed as a percentage of full-scale reading on any sensitivity range.

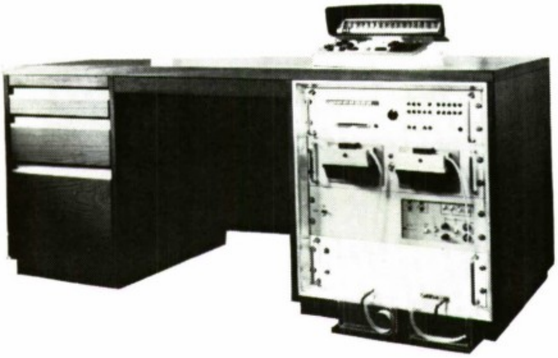

FIG. 6 (b). The processor.

measuring point all the input switches are closed simultaneously for a period of about 0·1 second, and then opened again. This causes each capacitor to charge to the instantaneous output potential of the corresponding oerstedmeter. Then, in the interval before the arrival of the next pulse, the output switches are closed momentarily in sequence, under the control of the logger. Since the logger will not accept the next measurement until the last has been punched on to the tape the recording system determines the maximum rate of acceptance of trigger pulses and, therefore, the maximum speed of the trolley.

Controls on the logger enable any number of oerstedmeters, from one to nine, to be scanned in sequence each time a pulse is received. In order to identify the measurements with respect to trolley position the pulses are applied to an electro-mechanical counter which displays the last measuring position passed, each unit representing an interval of six inches from the starting point. The same pulses are also counted electrically in binary-coded decimal form and the count recorded on the first channel of the logger on each scan. An arbitrary symbol (actually, the code for an ampersand sign) is punched onto the tape after each measurement as an " end of reading " instruction to the processing system.

The Processor

The data processor, of which a block diagram is shown in Fig. 5b, is based on a commercial electronic desk calculator controlled by means of an associated programming unit and fed with information by two tape readers instead of the normal keyboard. The output of the calculator is applied to a printer which types out the results of the analysis on a roll of paper and simultaneously punches a further paper tape with the same results in coded form. The various units forming the processor are built into a double-pedestal desk for convenience (Fig. 6b).

In order to carry out an analysis a punched card, or series of cards, is first inserted into the programming unit to instruct the processor on the operations it is required to perform. These cards carry information as to the numbers of magnetometers used and the sensitivity settings of the oerstedmeters and are selected from a small "library" according to the conditions at the time of the recording.

After the processor has been programmed a P + I record is, typically, inserted into one tape reader and the corresponding P record into the other. When the " start " button is pressed the first tape runs forward until the first piece of information on it, which is the number of the trolley position at the start of the run, is fed into the system and printed at the head of the first column on the paper roll. The second tape then steps forward in the same way until its initial number has been read and printed at the top of the second column. If all the starting conditions are correct these two numbers should, of course, be the same.

The processor proceeds to take the first P + I measurement from the one reader, store it and then take the corresponding P measurement from the other reader. It then subtracts the P reading from the P + I reading and types out the difference, which is the I value, at the head of the column corresponding to the appropriate magnetometer. When the readings of all the magnetometers in the first scan have been dealt with the paper is shifted to the next line and the second row of figures is printed in the same way.

As mentioned, the system is programmed to type out the first three significant figures of all results, with a negative sign if applicable. Normally the recordings are made with the oerstedmeters set to the ± 1000 gamma range and readings can therefore be taken up to 999 gamma to the nearest gamma. However, with suitable programming, the processor will accept recordings made at alternative oerstedmeter sensitivities.

Fig. 7 shows a section of a typical printed record for a set of measurements involving five magnetometers. It will be seen that, where a particular magnetometer is not used, the processor types a column of Os. The only manual intervention involved is in the identification of the record, which is inserted at the head of the sheet, using the printer keyboard.

CERTIFICATE NO. 3091 AXIS Z HEZ 440 HEX 0 Minus P RUN NO. L4 - L1

TRACK NO. CHANNEL NO.

TRACK NO.		0	0	3	4	5	6	7	0	0
40.0	40.0	.0	.0	1.0	1.9	1.6	1.7	1.1	.0	.0
41.0	41.0	.0	.0	1.7	2.4	2.6	1.9	1.1	.0	.0
42.0	42.0	.0	.0	2.2	3.8	4.1	3.9	2.3	.0	.0
43.0	43.0	.0	.0	3.4	4.8	6.4	4.5	2.3	.0	.0
44.0	44.0	.0	.0	4.5	7.5	9.3	7.1	3.9	.0	.0
45.0	45.0	.0	.0	5.8	10.5	13.3	10.4	5.9	.0	.0
46.0	46.0	.0	.0	7.6	14.1	18.5	14.1	7.3	.0	.0
47.0	47.0	.0	.0	9.0	18.6	24.2	18.7	9.6	.0	.0
48.0	48.0	.0	.0	10.6	22.6	29.7	22.9	11.6	.0	.0
49.0	49.0	.0	.0	11.8	25.7	34.7	26.4	13.1	.0	.0
50.0	50.0	.0	.0	12.4	27.8	37.[illegible]	28.5	14.1	.0	.0
51.0	51.0	.0	.0	12.1	26.9	36.2	27.5	13.5	.0	.0
52.0	52.0	.0	.0	11.4	24.6	32.5	25.2	12.6	.0	.0
53.0	53.0	.0	.0	9.8	21.0	27.1	21.5	11.1	.0	.0
54.0	54.0	.0	.0	8.2	16.9	21.1	17.1	9.2	.0	.0
55.0	55.0	.0	.0	6.6	12.5	15.7	12.4	6.5	.0	.0
56.0	56.0	.0	.0	5.1	9.0	11.0	9.0	5.3	.0	.0
57.0	57.0	.0	.0	3.4	6.5	7.6	6.4	3.7	.0	.0
58.0	58.0	.0	.0	2.3	5.1	4.6	4.4	2.5	.0	.0
59.0	59.0	.0	.0	[illegible]	[illegible]	3.2	2.3	1.3	.0	.0
60.0	60.0	.0	.0	1.5	1.9	2.2	1.7	1.0	.0	.0

FIG. 7. Middle section of the printed analysis from processor.

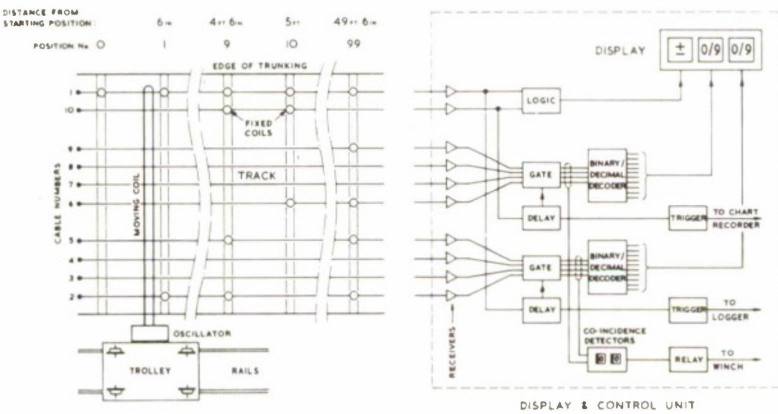

FIG. 8. Diagram of METRAC system.

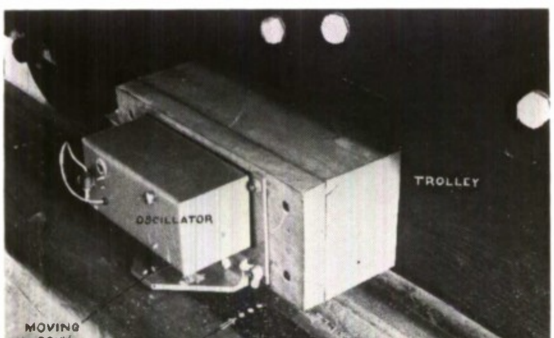

FIG. 9. METRAC oscillator and track.

Recordings of P measurements, which require no processing, can be read on one tape reader and typed out directly in the same format as the I values for convenience of comparison. Measurements of stray fields can be printed out if necessary by recording one set of measurements with the object unenergised and a second with power applied. The records are then subtracted from one another as for P and I records.

Measurement of Trolley Position

Development of the System

At the time it was decided to instal automatic digital recording equipment at the range it was appreciated that some means would have to be provided for producing marker pulses capable of

triggering the scanning circuit at intervals of a few inches along the track. At first sight it might appear that the simplest arrangement would have been to increase the number of micro-switches of the kind used as transit markers with the original chart recorders. However, the line of switches at 3ft. intervals had suffered considerably from mechanical damage and one or more were frequently out of action. This did not matter greatly with chart recording, since the position of the trolley could be determined by interpolation from the remaining pulses. Unfortunately, with the incremental counting system of the digital recorder, a single missed pulse would cause all the subsequent measurements to be one interval short of their correct track positions. Other disadvantages, such as cost and the cumulative magnetic effect of a large number of switches, led to their abandonment at an early stage of the investigation.

Various alternative systems were then considered, ranging from the use of a taut measuring wire paid out from a drum, to radar. Most of the schemes poposed however, either involved the use of magnetic materials and components or would have been too costly. The most nearly suitable arrangement seemed to be one involving the use of an optical projector mounted on the trolley and arranged to illuminate alternate light and dark stripes painted on the bed of the track. A photo-electric cell, also mounted on the trolley, would have detected the reflected light and conveyed the resultant pulses to the instrument room *via* a low-power radio transmitter.

In order to avoid the radio link it was then proposed that it could be replaced by an induction system consisting of a relatively low-frequency oscillator coupled to a pair of parallel wires forming a loop alongside the track. This led to the realisation that the optical measuring system was unnecessary, since the pair of wires forming the fixed coupling coil could be replaced with a line of small coils, connected in series, which would themselves determine the positions where signals from a moving coil, energised by an oscillator on the trolley, would be transmitted to receiving equipment at the end of the line. From this proposal it was a simple step to supplement the single line of coils with a group of additional coils at each measuring point whose presence or absence would define in code the actual position of the point. In this way the system could be made unambiguous and reversible to serve as a check on the incremental counter in the logger.

Description of the METRAC

The arrangement of the system actually installed at the Range, for which the name METRAC (Magneto-Electric Trolley Reversible Acatalectic Control) has been adopted, is shown in diagrammatic form in Fig. 8. The oscillator, which runs at a frequency of about 450kHz, is constructed from selected non-magnetic components and powered with a non-magnetic dry battery. The assembly is contained in an aluminium box, attached to the side of the trolley, from which the coupling coil projects. The coil, which consists of some 40 turns of wire, is about $\frac{1}{4}$in. wide and 2in. long, and is protected against accidental damage by resin encapsulation and aluminium guards.

The Track

The fixed coils are accommodated in a length of 2 in. square section electrical trunking in hard plastic. The trunking has a total length of rather more than the 50 ft over which measurements are normally made and contains 10 cables, each consisting of a single insulated and screened conductor. These cables run the entire length of the trunking and are extended at one end into the instrument room, while at the far end the conductors are electrically connected to their braided screens. At intervals of six inches a row of holes is drilled across the top of the trunking and at right angles to the track, Fig. 9. Each hole has a nylon stud fixed into it by fusing its upper end flush into the hole with its length projecting downwards. At each measuring point the conductors of those cables which are required to pick up the signal from the oscillator are pulled through their screening braid and passed round one side of a stud, the braid passing round the other side. In this way the required single-turn pickup coils are formed without the need to bare the wire or to make any joints.

Coding

Reference to Fig. 8 will show that cable number one has a coil formed at every measuring position and the resulting "units" pulses are used to trigger the logger and for gating the METRAC position display. Cable number 10 is similarly provided with coils at every

decade, *i.e.* positions 10, 20, 30, etc., and at the positions immediately preceding each decade, *i.e.* 09, 19, 29, etc. " Tens " Pulses from this cable are also required for gating the display and to provide five-foot marker pulses for a small chart recorder which is used for monitoring purposes.

The remaining eight cables are arranged as two groups of four. At each measuring position the cables of the first group (*i.e.* Nos. 2, 3, 4 and 5) are looped round the nylon studs, or left undisturbed according to the 1-2-4-8 binary code equivalent of the second (units) digit in the sequential (decimal) number defining the position. The cables of the second group (Nos. 6, 7, 8 and 9) are similarly grouped to correspond with the binary code equivalent of the first or " tens " digit in the position number. Thus, as the moving coil passes each measuring point the combination of signals appearing on cables 2 to 9 can be decoded to indicate the position of the trolley.

Display and Control

The 450 kHz signals are amplified and rectified with simple fixed-tuned receivers accommodated within the METRAC display unit, which is mounted adjacent to the logger in the instrument room. The visual presentation of trolley position is provided by a set of numerical indicator lamps which read from 0 to 99, prefixed with either a + or − sign. Normally, during measurement, the + sign appears. However, to facilitate the positioning of the trolley at the start of the measured section of the Range, prior to a run, the trunking is extended south of the starting point by a few feet, with measuring positions indicated with a negative prefix and numbers increasing as the trolley moves away from the zero position.

If it is desired to start a run nearer to the centre of the Range the trolley may be positioned at the appropriate place with the aid of the METRAC display and the counter on the logger set by hand to the same reading. To facilitate this operation a co-incidence detector circuit has also been fitted to the METRAC which can be set, by means of thumb-wheels, to the desired starting position. When the trolley reaches this point a relay operates and stops the towing winch.

Conclusions

The automatic recording and processing equipment described was installed at the Magnetic Range at the end of 1969 and has been in continuous use ever since.

After initial " teething " troubles, associated mainly with the control of the printer, the performance of the system has completely justified both its initial expense and the loss of working time while it was being installed. Whereas the P and I analysis of a set of measurements involving five or more magnetometers used to take one operator the best part of a week to carry out it is now possible to deal with each measuring axis in less than 20 minutes. As a result, the output of the Range has been increased by about five times and is now limited by other factors, such as the handling of the equipment sent for measurement.

It is sometimes said of electronic equipment that " if it works, it's obsolete ", and this cynicism might well be directed at the system described. In fact, if the installation were being planned again to-day it seems unlikely that " off-line " recording on punched tape would be adopted. In the three years since the system was designed data loggers have become available commercially incorporating small computers that no longer suffer from the disadvantages of equipment previously considered. A " computer-interfaced " logger of this kind would be able to store the measurements from several runs in its magnetic-core memory and then print out the separated results while recording was still in progress. Such a logger, costing no more than the present logger and processor together, would eliminate the processor as a separate piece of equipment and release its operator for other work.

SOME DIELECTRIC PROPERTIES OF AN EPOXIDE RESIN

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Abstract

As a means of examining the progress of the curing reaction, and molecular freedom, in an epoxide resin, measurement of the complex dielectric constant was found useful. The theory of dielectrics is discussed, and the results of the measurements presented.

Introduction

Epoxide resins are important and versatile materials which find many and diverse uses in modern industry and the Services. Applications include use as adhesives, casting compounds, laminating resins and encapsulation compounds. An epoxide adhesive was used in the museum restoration of the Dead Sea Scrolls, and epoxide casting compounds are used to repair damage to ships' screws. An important and much used casting resin is CIBA's Araldite CY 219, which is used with a Hardener HY 219 to promote chain and cross-link formation. Amongst its properties are good electrical and mechanical strength, high resistance to chemical attack and—particularly important for Naval applications—ease of use under adverse conditions.

An investigation of the 219 system was undertaken at RNEC Manadon, using an Electron Spin Resonance (ESR) spectrometer constructed in the laboratory. It was found that castings made from 219 exhibit ESR signals of considerable magnitude. The amplitude of the ESR signal depends upon the time which has elapsed since mixing the resin and hardener, becoming visible two days after mixing and reaching a more or less steady state seven days after mixing. These signals are believed to be due to the presence of unpaired electrons produced by separation of molecular segments in cases where there existed electronic interaction with anti-bonding character, and by actual bond-rupture. The separation and bond-rupture are attributed to the molecular re-arrangement which occurs during setting, and which is known to be accompanied by large internal stresses and visible shrinking of the casting[1]. During the investigation, it was desirable to gain some insight into the progress of the curing reaction, and it was considered that measurement of the dielectric properties during cure would be a direct and simple way of doing this.

Theory of Dielectrics

The theory of dielectrics is developed in Ref.[2] to give a result which can be used to make satisfactory predictions of the dielectric constants of gases and non-polar liquids. The results are expressed in terms of the properties of deformed electron clouds (electronic polarisation) and oriented molecular dipoles (orientation polarisation). Ref.[3] extends the theory so that it can be applied to polar liquids and simple solids. Taking into account only orientation polarisation, this leads to the following expression for the dielectric constant of a solid to which is applied a sinusoidally varying e.m.f., of angular frequency ω:

$$\varepsilon^* = \left[1 + \frac{Np^2}{\varepsilon_0 kT} \cdot \frac{1}{(1+\omega^2\tau^2)}\right] - i\left[\frac{Np^2}{\varepsilon_0 kT} \cdot \right]\frac{\omega\tau}{(1+\omega^2\tau^2)}$$

where N = the number of molecules having a non-zero dipole moment, per unit volume;

p = the dipole moment of a single molecule;

ε_0 = the permittivity of free space;

k = Boltzmann's constant;

T = the temperature in degrees Kelvin;

τ = the relaxation time of a molecular dipole.

The origin of molecular dipoles is discussed by Coulson[4].

Both valence-bond and molecular-orbital theory predict the existence of dipole moments, produced by contributions from the following:

(a) Asymmetry of charge distribution of bonding electrons· when an electron is more likely to be near one of the component atoms than the other;

(b) the homopolar dipole which results from inequality of size in the atoms;

(c) possible asymmetry (*e.g.* hybridization) of the atomic orbitals involved in the bond;

(d) the polarization of any non-bonding electrons.

It is conventional to quote molecular dipole moments in Debyes

(1 Debye $= 10^{-18}$ e.s.u. $= 3{\cdot}33 \times 10^{-30}$ coulomb-metres).

Values encountered lie in the range 0 - 10 Debyes.

The relaxation time of a molecluar dipole is defined on the assumption that, if a step-change of e.m.f. is applied to a solid, the growth of polarisation may be described by an exponential relation. τ is then the time taken for the polarization to reach ($^1/e$) of its final value.

Debye suggested that the relaxation rate is limited by friction, in the same way as the velocity of a body moving through a viscous medium, and on this basis developed an expression for τ, *viz.*, $\frac{6\pi\eta a^3}{kT}$

where a is the effective radius of gyration.

and η represents a transfer of angular momentum from the rotating molecules to the thermal motion of the lattice.

k and T are defined above.

The expression serves to bring out the $^1/T$ dependence of τ, which may be explained as follows:

The thermal energy although responsible for randomising the alignment of the dipoles and, therefore, reducing the number lined up, provides the kinetic energy to do the work against molecular friction, and so increase the speed at which they are able to line up.

$^1/\tau$ may be considered to represent the highest angular driving frequency to which the dipoles can respond. However, in general, η will be a function of temperature, so that the temperature dependence of τ will be less simple. Values of τ encountered vary over a very wide range (days to 10^{-12} seconds) depending upon the chemical composition, molecular structure, physical state and temperature of a material.

The electronic polarisation, which is not included in the expression for ε^*, simply increases the real part over the range of angular frequencies in which orientation polarisation is significant. When the angular frequency rises above $^1/\tau$ it becomes increasingly important and becomes, eventually, the only significant term. The theory is further extended in reference[5], and is applied to polymeric solids.

It is pointed out that some relaxations in non-polymeric solids produce results which may be predicted by the application of the single-relaxation-time theory outlined above, but that this behaviour has never been observed in polymers. It is invariably found in polymers that the observed curves, although similar in form to the single-relaxation-time curves, are never exactly duplicated by them. There are, however, two reasons why the single-relaxation-time model is important.

(a) First, the model may be generalised to give fit between predicted and experimental results. This is done by using several or, in the limit, a distribution of relaxation times.

(b) Second, dielectric relaxations are found to be thermally activated, and it follows from this that the exponential growth of polarisation in response to a step-change of applied e.m.f. is the only reasonable hypothesis.

In the same sense that the properties of real gases are understood in terms of deviations from the perfect gas model, so the properties of real relaxations may be understood in terms of deviations from the ideal relaxation: that is, a relaxation with a single relaxation time.

An expression for τ is obtained by considering a number of identical molecular segments which have two potential wells of equal energy available to them, separated by an energy barrier H. The equilibrium difference in populations between the two wells, resulting from the application of a step change of e.m.f., is attained exponentially, with time constant τ.

$\tau = \tau_0 \exp\left(\frac{H}{kT}\right)$, k and T having the usual significance.

$\tau_0 = (2\nu_0)^{-1}$ with $\nu_0 = \nu \exp(^S/k)$,

where ν = the frequency of vibration of the segments

and S = the change in entropy when one segment is brought to the top of the energy barrier between the wells.

The dielectric properties of a polymer may be observed by measuring the capacitance and resistance of a capacitor in which the polymer forms the dielectric. Consider a parallel plate capacitor, of plate area A, and let d be the plate separation. In vacuo, the capacitance C_o is given by $C_o = \frac{A\varepsilon_0}{d}$. If a sample replaces the vacuum between the plates, the capacitance becomes complex and is given by $C^* = \varepsilon^* C_o$. $\varepsilon^* = \varepsilon' - i\varepsilon''$ where

$$\varepsilon' = \left[1 + \frac{Np^2}{\varepsilon_0 kT} \cdot \frac{1}{(1+\omega^2\tau^2)}\right]$$

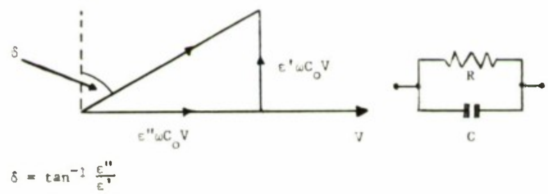
$$\text{and } \varepsilon'' = \left[\frac{Np^2}{\varepsilon_0 kT} \cdot \frac{\omega\tau}{(1+\omega^2\tau^2)}\right]$$

If an e.m.f. $V = \hat{V}e^{i\omega t}$ is applied across the plates of the sample filled capacitor the steady state current is given by

$$I = \frac{d(C^* \;\; V)}{dt} = C^* \frac{dV}{dt} = i\omega C^* V$$

$$I = i\omega(\varepsilon' - i\varepsilon'')C_oV = (\varepsilon'' + i\varepsilon')\omega C_oV$$

The in phase component, $\varepsilon''\omega C_oV$, accounts for a power loss in the sample.



The phasor diagram and a possible equivalent circuit are shown. The admittance Y is given by $Y = ^1/R + i\omega C$, and $I = YV = (^1/R + i\omega C)\,V$.

I may be written $I = \left(\frac{1}{\omega C_oR} + i\frac{C}{C_o}\right)\omega C_oV$

Then, by comparison, $\varepsilon' = C/C_o$,

and, $\varepsilon'' = \frac{1}{\omega C_oR}$

It is important to distinguish between dielectric loss arising from conductance in the sample and that from other sources, notably dipole relaxation. R may be considered to be the resultant of two resistors, R_o and R_1, in parallel, so that $1/R = 1/R_o + 1/R_1$

R_o may be used to account for the losses due to conductance, and R_1 for the losses arising from other sources, so that it is convenient to write $\varepsilon'' = \varepsilon''_o + \varepsilon''_1$, with

$$\varepsilon''_o = \frac{1}{\omega C_o R_o} \quad \text{and} \quad \varepsilon''_1 = \frac{1}{\omega C_o R_1}$$

R_o is independent of ω so that ε''_o varies as $(1/\omega)$. R_1 is, of course, frequency dependent so that the variation of ε''_1 is more complicated. R_o may be measured by a D.C. method whilst R, C_o and C may be measured by an A.C. method.

ε''_1 and ε' may then be calculated.

Measurement of these quantities was expected to give the desired guide to the progress of the curing reaction in a sample of (CY 219 and HY 219), used as dielectric in a parallel plate capacitor.

HY 219 was known to have rather a low resistivity which may be attributed to the presence of ions. It was expected, therefore, that on the addition of CY 219, the increase in viscosity would reduce ionic mobility and produce an increase in R_o.

$$\text{Also, } \varepsilon''_1 \left[= \frac{Np^2}{\varepsilon_o kT} \cdot \frac{\omega\tau}{(1+\omega^2\tau^2)} \right]$$

has a maximum at $\omega = 1/\tau$ for a single relaxation time model. If a distribution of relaxation times is appropriate, a rather flat curve will result from plotting ε''_1 against ω, but there will be a maximum, even though less sharply defined.

If, instead, measurements are taken at a single frequency and τ is varied, similar results will be obtained. The Debye expression for τ, *viz.* $\tau = \frac{6\pi\eta a^3}{kT}$, suggests an increase of τ if the quantity η (which is analogous to viscosity in linear motion) is increased. It was expected that change of η with the progress of the curing reaction would show up in a curve of ε''_1 vs time, at constant frequency.

$$\text{Again, } \varepsilon' \left[= 1 + \frac{Np^2}{\varepsilon_o kT} \cdot \frac{1}{(1+\omega^2\tau^2)}, \right.$$

$$\left. \text{neglecting electronic polarization} \right]$$

falls off with increasing ω or increasing τ. It was expected that change of η with the progress of the curing reaction would also show up in a curve of ε' vs time, at constant frequency.

Measurements On the basis of the theory outlined above, it was decided to take a small tuning capacitor, measure its capacitance, encapsulate it and make the following measurements:

(a) D.C. resistance between terminals using a D.C. bridge.

(b) Resistance and capacitance between terminals at a low frequency, $\sim 10^3$ Hz, using an A.C. bridge.

(c) Resistance and capacitance betwen terminals at higher frequencies using a Q meter.

Results The results obtained for $1/R_o$, ε''_1 and ε', respectively, are shown in Figs. 1, 2 and 3. The D.C. bridge used to measure R_o gave a value of infinity, after rather less than four days from mixing, showing that the expected decrease in D.C. conductance took place. Curves of the general form expected resulted from plots of ε''_1 vs time each at constant frequency. Each curve shows rather a broad maximum, and the family shows the increase of τ with progress of the curing reaction. Reference[5] discusses in considerable detail the various loss peaks which may be observed in polymers. The loss peak occurring

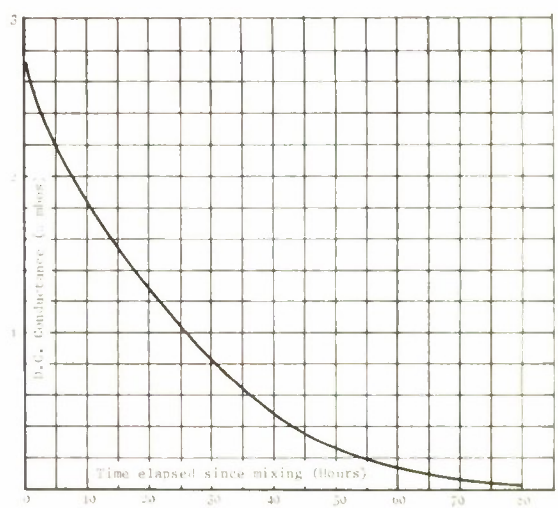


FIG. 1. Variation of D.C. conductance during cure.

at lowest frequency (at a given temperature) is designated the α loss peak; subsequent peaks are designated β, γ, etc., in order of increasing frequency.

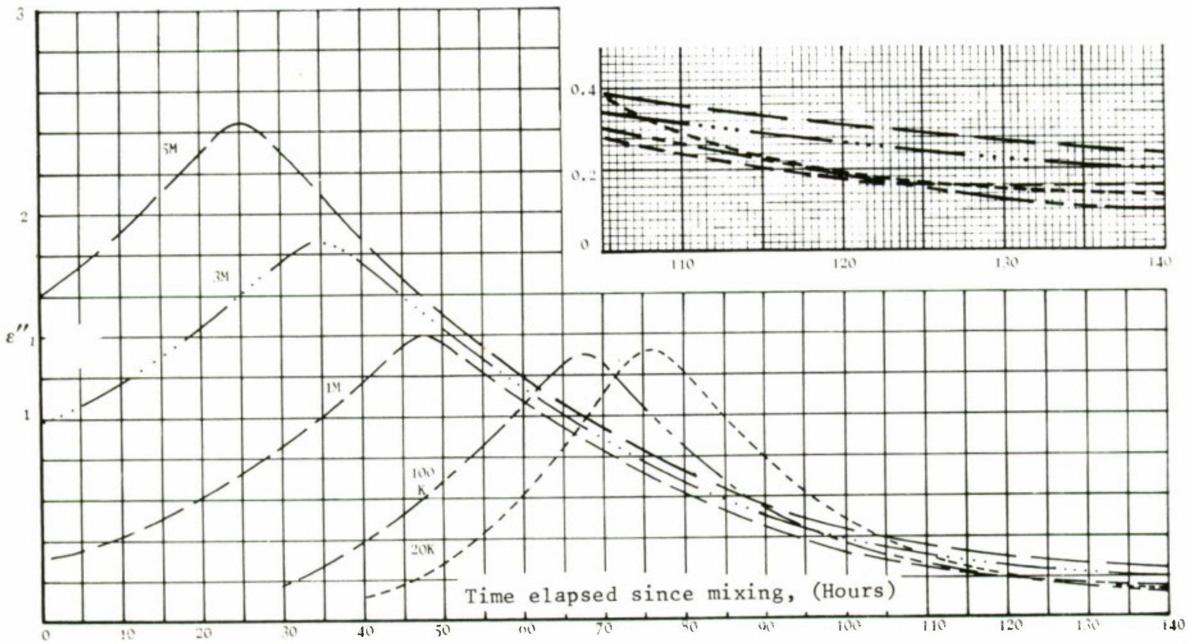


FIG. 2. Variation of ε''_1 during cure. Frequencies: 20kHz, 100 kHz, 3MHz and 5MHz.

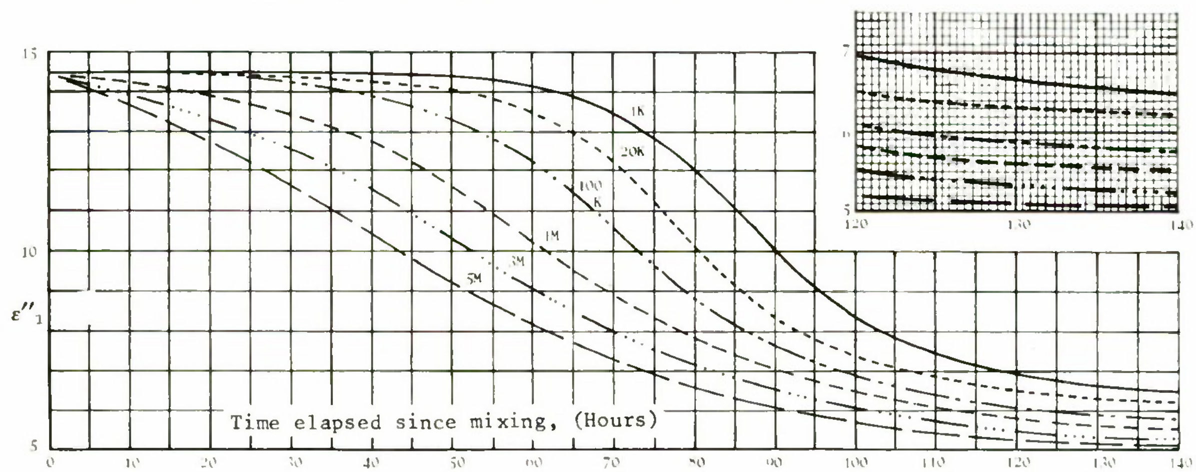


FIG. 3. Variation of ε' during cure. Frequencies: 1kHz, 20kHz, 100 kHz, 1MHz, 3MHz and 5 MHz.

The α loss peak is attributed to large-scale conformational re-arrangements of the polymer chain backbone, occurring by a mechanism of hindered rotation around main-chain bonds. That mechanism is not possible when the polymer has attained a glass-like state. The subsequent loss peaks may be attributed to the hindered rotation of side groups, since that mechanism can occur to some extent at all stages of cure. There was some evidence, from measurements taken at 100 kHz, 20kHz, 1 kHz and 100 Hz, that suggested the occurrence of smaller loss peaks at early stages of the cure, before the principal peaks were reached. However, as explained above, evaluation of ε''_1 is carried out by multiplying the difference

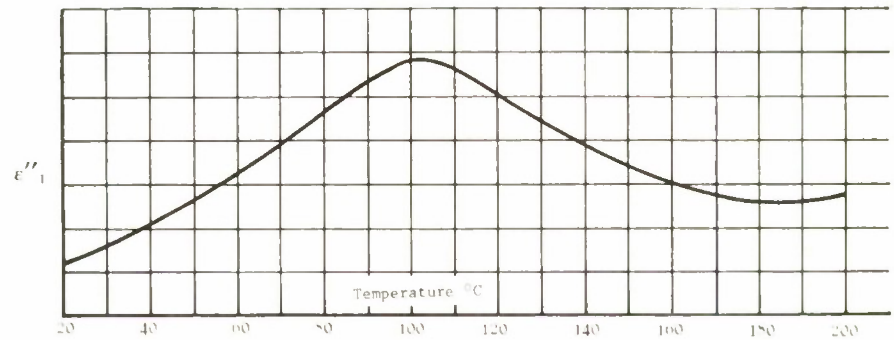


FIG. 4. Variation of ε''_1 with temperature at constant frequency.

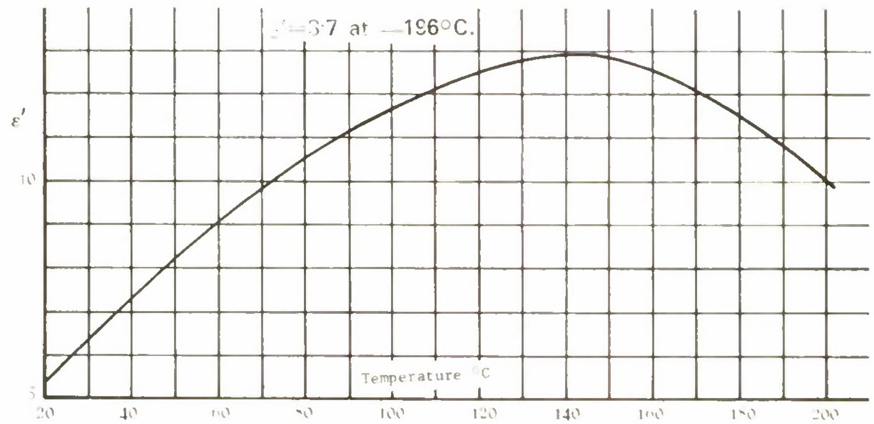


FIG. 5. Variation of ε' with temperature at constant frequency.

between A.C. and D.C. conductances by a factor $^1/\omega C_0$. In the early stages of cure at 100 kHz and 20 kHz, and over a great deal of the range at 1 kHz and 100 Hz, that involves multiplying a small difference by a large factor. A more refined measuring technique than that employed is necessary in order to examine the low frequency range of ε''_1. The principal peak may be attributed to hindered rotation of a side group. The O-H groups are likely to undergo rotation and make some contribution, perhaps even the main contribution, to this effect. The family of curves of ε' vs time, each at constant frequency also brings out the expected decrease in dipole response as cure proceeds. Both families of curves suggest that the value of dipole mobility is not close to its steady state value until about five days after mixing, so it is presumably only then that a rigidity approaching the final value is obtained.

Further Investigation

It was observed that post-cure heating of a sample, which exhibits a large ESR signal, results in the signal going to zero initially and then increasing slowly to reach a steady state value which is typically 1/10 the original signal. This behaviour is attributed to molecular freedom, induced by thermal activation, allowing movement to reduce internal stresses. Again it was considered that a measurement of the dielectric properties would provide information about molecular freedom. In this case the resistance and capacitance between terminals of a specimen similar to that used previously, were measured after cure was complete, at fixed frequency and various temperatures. The results, plotted in Figs. 4 and 5, show that a considerable increase in mobility occurs as the temperature is raised. The behaviour of the curves, particularly that

of ε' vs temperature, suggests that some takes place at about 140°C. It is not unreasonable to expect the glass-transition temperature to lie in this region, and that transition may account for the observed results.

Conclusions

The simple measurements described, which were made with the use of readily available and easily portable apparatus, allow some estimate of a curing reactions progress to be made. The temperature dependence of the measured properties must be remembered if the technique is used to follow cures carried out at various temperatures.

Acknowledgements

We wish to thank Rear Admiral N. H. Malim, M.V.O., for permission to publish this work.

We are indebted to Mr. D. Griffiths, R.N.S.S., for providing materials and information, and to Mr. H. W. Jarman for his skill and care in preparing samples.

References

(1) Lee and Neville, *Handbook of Epoxy Resins*, McGraw Hill, 1967.
(2) Feynman, *Feynman Lectures on Physics*, Volume II, Addison-Wesley, 1964.
(3) Kittel, *Introduction to Solid State Physics*, 3rd Edition, Wiley, 1966.
(4) Coulson, *Valence*, 2nd Edition, OUP, 1965.
(5) McCrum, Read, Williams, *Anelastic and Dielectric Effects in Polymeric Solids*, Wiley, 1967.

NUCLEAR SYMPOSIUM AT THE ROYAL NAVAL COLLEGE, GREENWICH

A Symposium entitled "The Chemical Technology of the Pressurised Water Reactor and its Safety Implications" was held in the Department of Nuclear Science and Technology, Royal Naval College, Greenwich on 26 - 27 July. Of interest to all those concerned with operating, maintaining, building and designing the Navy's nuclear submarines, papers were presented under the headings of

Corrosion of Reactor Materials,

Primary Circuit Radiochemical Problems,

Secondary Plant Problems,

Problems during building and maintenance, and

Health and Safety implications.

Contributions were from the Royal Naval College, Rolls Royce and Associates, FOSM UKAEA, Victor and C.E.D. An exhibition illustrating the wide range of techniques used for studying corrosion of materials and materials testing, measurement of radioactivity, water chemistry and other analytical procedures was also presented. A Symposium report and selected papers will be published in the *Journal of the Royal Naval Scientific Service*.

AUTOMATIC HEADING AND TRACK KEEPING CONTROL

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Brian Spencer graduated from Leeds University in 1950 with an honours degree in mathematics. National Service 1950 - 52 as a flight engineer in the Royal Air Force Transport Command. Worked as an engineer in the ramjet development department of the Bristol Aeroplane Company Engine Division 1952 - 55. Moved to the Gloster Aircraft Co. and worked on the stability and control of aircraft from 1955 - 1958. Joined the Ministry of Defence as a Senior Scientific Officer in 1959 and until 1965 worked at the Admiralty Experiment Works on the stability and control of submarines. Transferred to Bath and promoted to principal scientific officer in 1965, and at present employed in the department of the Scientific Adviser to the Director General Ships. Out-of-office activities include music (listening to, playing, and teaching) and golf.

Introduction

An autopilot has recently been developed by S. G. Brown Ltd. in conjunction with MOD(N) to a MOD(N) specification. The prototype version has had sea trials on H.M.S. *London* and H.M.S. *Exmouth,* and eventually all H.M. Ships will be fitted with this type of automatic steering equipment. The autopilot satisfactorily controls a ship's heading, but it is proposed, if possible, to adapt the same unit so that a ship can be steered automatically along a specific track (*i.e.* over the ground). A method which involves the transmission to the autopilot of a continuous updated demanded heading angle in order to maintain track has been subject to computer study.

Heading Control

Fig. 1 is a photograph of the control position of the prototype version of the autopilot. When auto-steering the large control knob in the top right-hand section of the panel is used to set the desired course. Rotation of this control initiates automatic course changing, the ship's heading changing to the new set course in the same direction as that in which the control is rotated. The maximum amount of rudder used in any manoeuvre (couse keeping or course changing) is limited by the knob in the top left-hand section of the panel; it can be set to values between 3° and 35°.

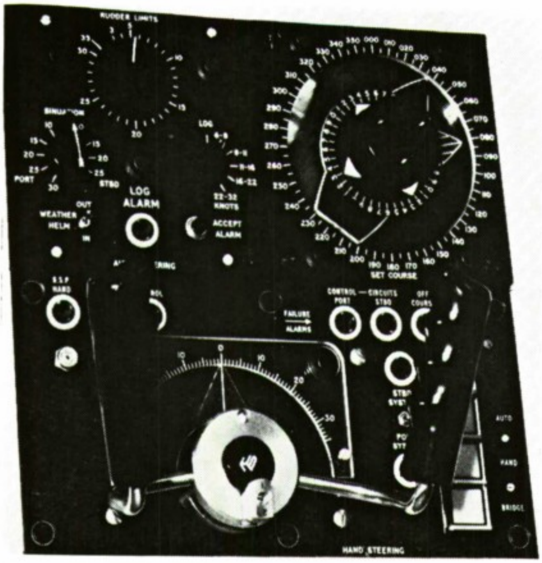

FIG. 1. Autopilot Control Console.

The equipment is designed so that its response adapts automatically to changes in ship's speed. For the prototype trials, however, a suitable ship speed signal was not available, and compensation for different ship speeds had to be made by using the five position control switch shown below and to the right of the rudder limit control.

The weather helm switch is also on the control panel. With this switch in the 'out' position the autopilot is effectively a proportional control in that non-zero rudder angle is only achieved if there is a heading error. Thus on any course demanding weather helm the control would steady the ship on a course differing from the set course by an amount sufficient to provide some non-zero rudder angle. With the weather helm switch in the 'in' position an integral term is introduced into the control equation, and rudder angle is applied until the heading error is reduced to zero.

The bridge manual steering position is also on the console. Not shown in the photograph, however, is the hand held course changing unit which can be connected by a long lead for use on the wings of the bridge, for re-fuelling at sea, for example. In this unit there are two buttons (port and starboard) and a single press of either of these buttons injects a demand for a $\frac{1}{2}°$ course change (in the appropriate direction) into the autopilot.

The sinuation control shown on the prototype equipment provided automatic weave about the mean course. It will probably not be incorporated in future versions.

Operating Principle

The difference between the ordered heading and actual heading is measured and used to compute the desired corrective rudder angle.

The control equation is:

$$\delta(t) = -K\left(\frac{1+Ap}{1+Bp} + \frac{E}{p}\right)\Big[\psi_0(t) - \psi(t)\Big]$$

Where δ is the rudder angle, ψ_0 is the ordered heading, ψ is the actual heading, p is the differential operator, and K, A, B, E are control coefficients. The control coefficients are selected so that on a particular ship K remains fixed at all times, and A, B, E are programmed to vary (keeping A/B constant) so that similar performance is obtained at different ship speeds. When A, B, E cannot be varied automatically they are changed by using the five position speed compensation switch (as on the prototype version). The integral (or weather helm) term E/p is switched 'in' or 'out' by the weather helm switch, and when in operation it decays automatically whenever the heading error exceeds 10°.

In the trials ships the rudder demand signal produced by the above control equation was transmitted to the after power unit, in which an electric motor drove a linear rack such that its longitudinal displacement was proportional to the desired rudder angle. The linear motion of the rack moved one end of a differential lever, the middle of which was attached to the hydraulic pump control, and the other end to the tiller arm of the rudder. Thus movement of the rack caused the hydraulic pump to supply oil to the rams which moved the rudder until the differential lever was re-aligned in an equilibrium position. The rudder angle obtained was proportional to the rack position which was equivalent to the desired rudder angle. The capacity of the hydraulic power supply limited the maximum rate of rudder movement to about $2\frac{1}{2}°$ per second, and this maximum rate was only achieved when the demanded rudder angle exceeded the actual rudder angle by a pre-determined amount (variable between 2° and 8°). For smaller differences the rudder rate obtained was proportionately reduced. The maximum rate of movement of the after power

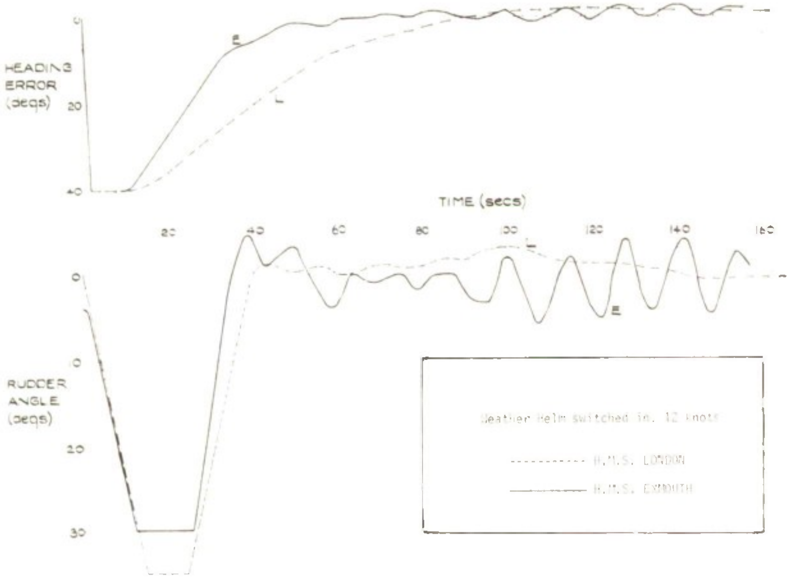

FIG. 2. 40° Auto Course Change.

unit rack was a little faster than the maximum rudder rate, and the rack rate was also proportionately reduced when the difference between the actual rack position and the demanded position (from the autopilot) was less than a band of a few degrees. These proportional rate limitations avoided the use of dead zones which are usually necessary when a system is of the bang-bang type.

Trials

During the trials on H.M.S. *London* and H.M.S. *Exmouth* the automatic control of steering was in general equal to, and in some manoeuvres superior to, manual control by an experienced helmsman. When course keeping the heading error was within ±0·5° in state 2 seas, the error increased to ±1·5° in the state 4 and 5 seas encountered during the *Exmouth* trials. However, a state 5 sea on *Exmouth's* following quarter produced heading errors of up to ±5°; a helmsman could not improve on this performance.

Course changing manoeuvres were generally quite satisfactory, although with the weather helm integrator switched in, the overshoot obtained was a little disappointing. It was, of course, appreciated that the integral term would produce some overshoot (the reason for making the accumulated integral decay when the heading error exceeded 10° was to reduce the overshoot), but it was possible to obtain 2° of overshoot irrespective of the magnitude of the course change, or the ship speed. The heading errors and rudder angles recorded during a 40° course change at 12 knots in both ships are shown in Fig. 2 (greater sea disturbance during the *Exmouth* trial).

For the H.M.S. *London* trials the control coefficients were K=2, A/B=4, and for H.M.S. *Exmouth* K=1, A/B=4. Computer studies indicate that for these ships better course keeping could be obtained with higher K values, and these will be tried in future installations on ships of a similar size. A modification to reduce the overshoot obtained when using the weather helm integrator is also being considered. (This modification was proposed by Professor K. V. Diprose of Bath University, who acted as consultant to S. G. Brown Ltd. during development of the autopilot.)

Track Keeping

The heading control described maintains course, but clearly the same autopilot could be used to maintain track (over the ground) if the ordered heading was continuously varied by amounts proportional to the ship's distance off the desired track. To maintain track automatically the autopilot control equation would have to be of the form:—

$$\delta(t) = -f(p)\,[\psi_o(t) - \psi(t) - \psi_t(t)]$$

where $f(p) = K\left(\dfrac{1 + Ap}{1 + Bp}\right)$

K, A, B are the autopilot heading control

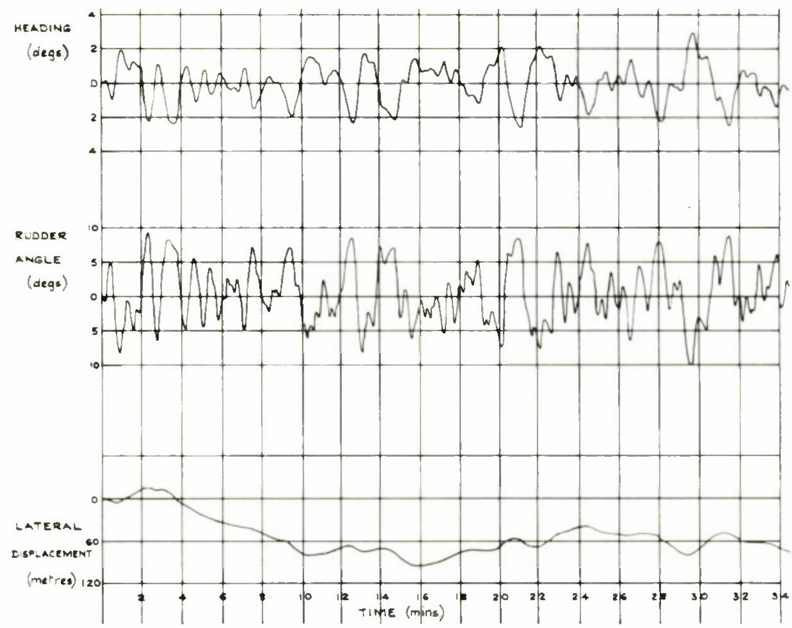

FIG. 3. Simulation: Autopilot Course Keeping three knots.

coefficients (note that the weather helm integrator term is not included, and must not be used in the track keeping mode), and $\psi_t(t)$ is an additional signal computed from the distance off track, Y (in metres). A suitable form of the function $\psi_t(t)$ was determined by computer study such that:—

$$\psi_t(t) = \left(k_1 + \frac{k_2}{p} \right) Y$$

where k_1, k_2 are additional control coefficients. Thus for automatic track keeping the distance off track would have to be calculated continuously or at discrete short time intervals by reference to some known position (e.g. line of buoys, or position fixing network), and $\psi_t(t)$ computed and transmitted to the autopilot in suitable form.

Simulation Initially track keeping would be used by survey vessels, or ships carrying out specific search patterns, hence a ship with characteristics similar to those of vessels undertaking these operations was simulated on an analogue computer. The heading control was also simulated and the autopilot control coefficients K, A, B providing the most suitable response (throughout the speed range of the ship) were estimated. If, as before, K (the overall gain) was to remain fixed, suitable values were $K = 1{\cdot}5$, $A/B = 6{\cdot}0$. However, it seems likely that a ship of this type would have to operate for long periods at low speeds (*e.g.* less than six knots), and it was found that at these speeds the simulated ship kept better course in response to a pseudo-random disturbance if the K value was increased to 3·0. It was not practicable to use this higher K value at all speeds, and hence for this type of application it may be found necessary to provide means whereby K can be varied. A section of course keeping record is shown in Fig. 3.

When automatic track keeping was simulated it was again found that the best performance at low speeds was obtained with the higher K values, whatever the values of k_1 and k_2 (the additional coefficients), although, of course, high K values necessarily produce larger rudder angles. A further significant feature of the simulated automatic track keeping was the large variation of heading angle necessary to maintain track at low speeds. The computed signal $\psi_t(t)$ was limited to prevent the generation of excessive heading changes, and it was also found that by using lower k_1 and k_2 values the heading variation was reduced without too marked an increase in distance off track. A section of track keeping record is shown in Fig. 4. This result was obtained by assuming that the distance off track was measured accurately and continuously. Other results were obtained assuming that the distance off track was measured every two seconds, and that there was a random error of up to 18 metres in the

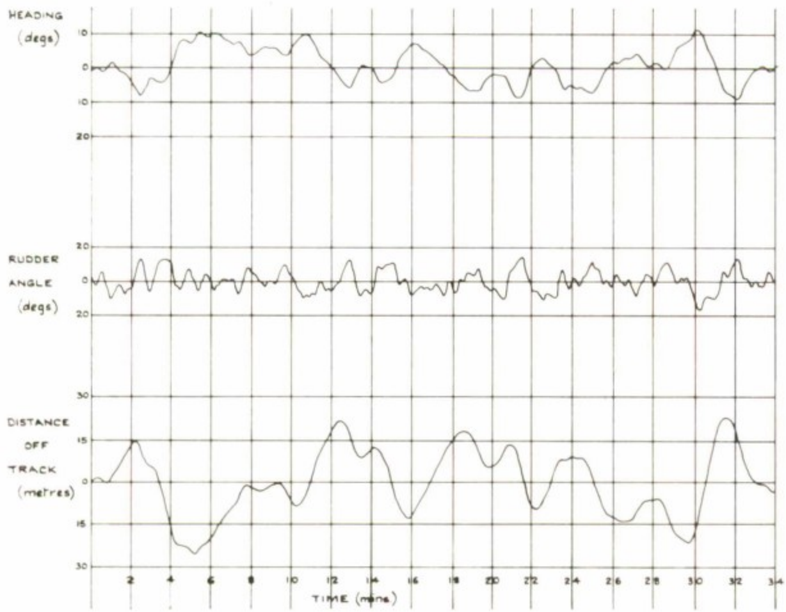

FIG. 4. Simulation: Auto Track Keeping three knots.

The effect of increasing the rudder rate from the normal rate of about 3° per second was also investigated. Faster course changing could be achieved, but with the same autopilot coefficient settings there was little noticeable effect on course or track keeping. However the faster rudder rates did make it possible to use higher K values, and so improve course and track keeping. It appeared that some advantage could be gained by increasing the rudder rate to about 6° per second.

measured value. The use of this more realistic measured distance to calculate the desired rudder angle resulted in much greater rudder movement and an increase in the distance off track variation of some 20%. Filtering the measured distance signal reduced the rudder movement, but further increased the deviations from the desired track. The effect of a steady disturbance (wind or tide) was also simulated; this was of interest because of the large deviations from the desired track that could be obtained on engaging the track keeping control, unless the ship was initially heading into the wind or tide.

Further Studies

In the above investigations the simulated after power unit was of the proportional rate type described in an earlier paragraph. This unit could be replaced by one of the bang-bang type with an adjustable dead zone to prevent continuous oscillation. Such a unit was simulated and it was found, as expected, that for very small dead zones there was little difference between the two control systems when course or track keeping. Larger dead zones could, of course, be used to cut out small rudder movements, a method adopted in some existing autopilots (often referred to as yaw control). By this means short periods with the rudder stationary could be obtained, but again as expected the simulation showed that there was some deterioration in course and track keeping performance.

Conclusions

When a suitable ship speed signal is available this newly developed autopilot can be used satisfactorily at all speeds without any manual adjustment. Automatic heading control is, in general, at least as good as control by an experienced helmsman, and further improvement is undoubtedly possible. Such improvement, however, particularly in course keeping involves the use of larger rudder angles, and large angles are not always desirable even if they are necessary for more accurate control.

A simple but reasonably realistic simulation of a ship and autopilot has been used to show that it should be possible to use the same autopilot for track keeping, provided that the distance from the desired track can be measured and suitably processed to produce an additional input to the autopilot. But if accurate track keeping is required at low speeds it is almost certain that an additional variable control will have to be made available on the console, so that the overall gain K can be changed.

Although at present track keeping ability is only being considered for certain specialised operations, all navigation ultimately requires the maintenance of track rather than course. Thus eventually many more ships may be fitted with track keeping equipment, using an inertial navigation system or some world-wide position fixing network for measuring the distance from the desired track.

RESEARCH AND DEVELOPMENT MANAGEMENT IN THE NAVY DEPARTMENT

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The substance of this contribution to *J.R.N.S.S.* will be confined to that part of the Ministry of Defence known as Ministry of Defence (Navy) (MOD(N)) or perhaps more colloquially the Navy Department. Whilst the Ministry of Defence is concerned with defence as a whole, the Navy Department is responsible for all matters in the naval and maritime field.

The total level of the National effort for defence is of course determined by the Government of the day, after consideration of their defence policy and in the light of all the other activities. The Ministry of Defence has a powerful Central Staff and a number of senior committees which assist in determining the constitution of the military forces, what they are for and how they should be deployed etc. The Research and Development policy is only one aspect amongst many others and the Central Staff work out the main guidelines of general policy and the allocation of resources. The committees principally concerned in this field are the Weapons Development Committee (WDC), the Operational Requirements Committee (ORC) and the Defence Research Committee (DRC) and their role in the context of MOD(N) will be referred to later. As is well known the whole Government programme is forecast well ahead in the Long Term Costings, the defence element being one of the major headings.

Any form of management control has some similarity to automatic control of a very complex mechanism in that there are feedbacks in local control loops and there is a connection between the top and the bottom of the system. Any organisation is, however, more like an animal than a simple mechanism as it has its own built-in adaptive facilities. If morale in an organisation is high people involved work out satisfactory ways of achieving the end-product they deem important. In old organisations the system often works in a different way from that shown on the organisation charts; it may even be difficult to find out how it really works. In almost all cases it is probably impracticable to show on any organisational diagram anything other than the more formal control lines.

The comments that follow are relevant to the organisation of control of R & D in the Navy Department and illustrate the current methods for controlling this part of the programme. It must always be remembered that the development of a new piece of complex equipment often takes up to 10 years from its conception to its use in the Service and that this prevents, or at least inhibits rapid changes in procedures.

Looked at in a very simplified form the MOD(N) system at present works, for the main part, as a series of "go"—"no go" tests applied to propositions fed in at low level. If a propositions gets a "go" at all levels, or at the appropriate level, it will appear as a work item.

This article is based on the substance of a talk given by the Deputy Chief Scientist at a Colloquium on Management of Research and Development held at the Department of Electronics, Southampton University, March 24th, 1971.

Individual Projects

Consider the diagram shown in Fig. 1 at a particular point of time. The R & D establishment, responsible for certain R & D activities, will have a full work load, all of which has been approved. It is the Director's complete responsibility to manage and control all the Research and all the Development, whether it be "in house" or extra-mural in industry and the universities.

Continuous contact is maintained between members of the R & D team and those of the Naval Staff, the latter being charged with applying their minds to all aspects of future naval warfare, in which they are assisted by experts in operational analysis. These to and fro activities, which occur at Principal Scientific Officer and Commander level, may throw up the need for a new item of military hardware, one that will make a significant advance in the capability of the Royal Navy.

mittees of the Ministry of Defence. This should ensure that propositions fed in at the bottom have an opportunity of being given a "green" light all the way to the top if they need go that far. Approval for small projects is delegated to levels below the WDC and certain projects, for example, can be authorised by the Naval R & D Board.

Suppose examination has disclosed the need for a new weapon. The Establishment, together with the Naval Staff, make out a case for the new article considering the following points.

The merits of the weapon, if it were to exist, must be discussed for a variety of likely military situations. It must be shown to be a marked improvement on existing weapons and that the cost both R & D-wise and when fitted in ships is not high, relative to its military worth. In some cases this can be quantified and this is done whenever possible. Technical problems are outlined and the costs year by year for both the

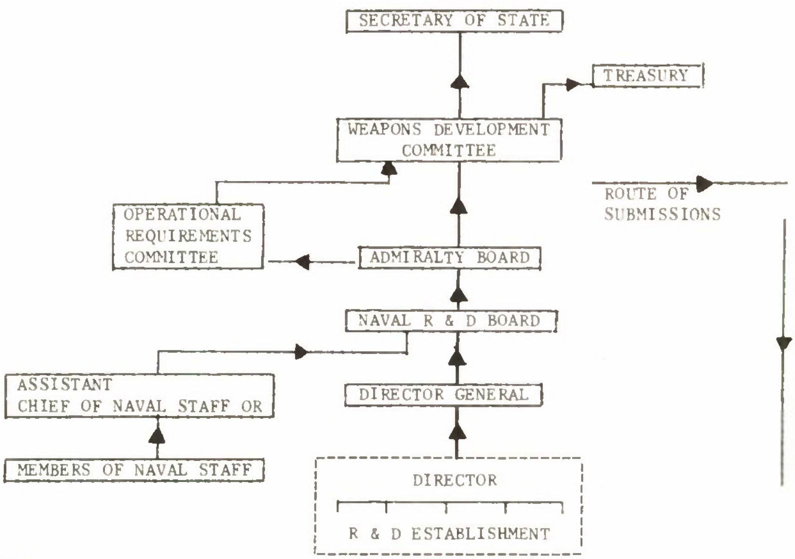


FIG. 1. Flow diagram.

It must be remembered that guidance is flowing in at all times from the broad stream of information flow shown on the right of the diagram in Fig. 1, and it should be noted that it is a two-way flow. The downward flow of information and directives come from Government policy as declared by the Secretary of State and elaborated by the senior staff and senior com-

R & D and for production, all at current prices, are given. The merits and demerits contrasted with equivalent foreign weapons are also appraised. If the weapon is very attractive, it may well be that foreign sales will be possible. If a foreign weapon can be purchased at a price more favourable than home R & D it may be advisable to purchase abroad and

reserve R & D, which is generally considered a scarce commodity, for more worthwhile work.

As in most cases development is carried out by industry, the costs that are considered are the total industrial costs together with the internal costs in MOD(N) of managing the project and providing any supporting services. Costs are always worked out on the basis of current pay and prices and inflation is allowed for by up-dating at intervals.

A proposition formulated in an R & D establishment and blessed by the Director General in charge of the Department is first considered by the Naval R & D Board. This Board is chaired by the Chief Scientist (RN) and consists of the Assistant Chief of Naval Staff (Operational Requirements), the Under Secretary responsible for Material and the Deputy Chief Scientist (Naval). It may ask for modifications to be made to a proposition, can reject it, but usually for the reasons given above, finally puts forward a proposition, possibly modified after discussion with the sponsors, to higher authority. If approved by the Admiralty Board the proposition comes before the Weapons Development Committee, whose interests cover all three Services. Before the proposition is taken by the WDC it must be blessed by the Operational Requirements Committee. This committee, which also considers all the military requirements of the three Services must be satisfied that a genuine military need exists. The Naval R & D Board, together with the higher boards and committees must be assured that the Navy has adequate resources to nourish the new project. For a more full account of this part of the Ministry of Defence reference should be made to the Second Report from the Select Committee on Science and Technology, Session 68 - 69.

An item of Research is treated in a similar manner. It is not referred to either the ORC or the WDC, however, but to the Defence Research Committee which has a standing comparable to the WDC.

When any weapon system escalates by more than 10% it must return over the various hurdles and receive re-endorsement if it is to continue. This unfortunately happens rather too often, due to the difficulty of estimating problems in the development of advanced projects. There is also a tendency to try and make the project appear attractive, so that it gets a fair wind.

Long Term Costings and Estimates

It will be appreciated that a new item can only appear in the programme if the Navy Department has the funds and manpower available.

Each year money is voted by Parliament against the Estimates and each Government department is responsible for ensuring that money is properly spent as voted, neither more nor less. For example, the money voted for Research and Development and other scientific services for the Navy in 1969 - 1970 was £37,501,000. Estimates are, however, only concerned with the year to which they apply but planning must take place against a far longer time scale and is done on a 10 year basis. The first five years should be reasonably realistic, prognostications for the next five years are far more uncertain.

It will be understood that at any one point in time some items in the research and development area are likely to be just completed, some in full flight, some near completion, others newly started and some only just gleams in the eye.

If the allocation of resources, both men and money, was constant, new activities could be taken on to balance those completing. Individual items would be submitted in the way previously described and if these new items satisfied the total naval demand for new systems, all conditions would be met. If the needs were not quite met some projects would have to be delayed a little until funds and men were available. The changing importance of various aspects of naval warfare is allowed for by a gradual build-up in certain areas, possibly at the expense of others. Directors of Establishments and their Directors General are given guidance as to their probable allocation of resources for the 10 year planning period.

There are two controlling factors, the first is that the total financial bill for MOD(N) falls within its slice of National resources, the second is that its share of what is deemed a proper figure for defence R & D as a whole is not exceeded. As is to be expected a larger share of the cake is always most welcome and each Service presses not only for a larger slice but also a larger cake. Under the U.K. constitution the final decisions are those of the elected Government of the day.

When resources are reduced, especially below what appeared in previous plans, it is especially difficult to start new work, and some running

project may even have to be cancelled. The chief difficulty in planning, however, is the tendency of project sponsors to underestimate what their costs will be, not only as regards R & D, but also as regards production costs. This appears to be a general problem for which there is no easy solution. It is by no means unknown for firms to get themselves into serious trouble when they undertake to do a clearly defined piece of development against a fixed price. Until the estimate expenditure bears some reasonable relationship to what eventually happens, even the best attempts at forward planning still result in much frustration and some abandoned projects.

As has been said previously, if a project escalates by more than 10% it has to go back to the committees that originally gave approval.

The escalating cost can result in a marked increased cost per annum, or the work can take much longer, or it can be a mixture of both. Although a lengthened time scale eases the immediate problem of containing the total R & D activity inside a yearly budget, it does so by inhibiting taking on new work and also means that the project is already getting dated by the time it emerges.

It is unfortunately not sufficient to estimate costs as accurately as possible and then to apply a safety factor. R & D in very advanced areas invariably rises to mop up the money allowed for the project and then to rise above it.

Directors, against the guide lines given, draw up their programmes usually asking for more resources. They are well placed to decide their programmes as they are experienced people, knowing what is wanted and what resources are available. The Department at Admiralty Board level, and in consultation with the Central Staff, finally adjusts the programme by moving items in or out, or delaying them until the programme and the allowed resources match. Occasionally a project is put forward offering a number of solutions at different costs, thus allowing more selection.

It is found that if various projects are given sums which must not be exceeded then the total money spent in one year is below the summation of the individual amounts. This happens because some projects start late, but is also caused by the imposition of upper limits which tend, due to tolerances, to make the sum actually spent fall below the maximum. Allowance is made for this factor.

The appearance of an item in the Long Term Costing does not give authority for it to go ahead. It must pass the hurdles previously described and receive Treasury approval. As the Treasury is represented on the WDC this is not a serious obstacle provided the total demand is within the expected figure.

The system depends very heavily on sound judgment by Directors of Establishments and all the staff at the " working level ". Too exotic activities in one field of their parish almost certainly means that other fields are left untilled. If, however, R & D resources do not allow proper coverage over the parish one solution would be to buy foreign or to have collaborative activities with another nation. Alternatively, a relatively greater slice of the defence cake could be spent on R & D.

It must be remembered, however, that frequently the R & D cost in the Defence Field is of a comparable order to the total production cost and increased R & D cost often means increased production cost. An increase of the total Defence Vote requires governmental blessing and parliamentary approval.

The preparation of the R & D programme demands a significant part of the total effort of senior officers. The Long Term Costings are in preparation in the winter and spring months, with the Estimates being prepared departmentally about six months later. These now tend to take the form of updating the next years of the Long Term Costings.

Directors of Establishments normally have a group of analysts on assessment work to aid them in reaching decisions. Such a group assesses the merits of individual weapon systems and some aspects of the interplay between systems. Broader studies are undertaken at MOD(N) headquarters and are also carried out by the Defence Operational Analysis Establishment. Analytical work of this nature is not only very time consuming but demands able and experienced people.

Although there is a desire in some quarters to strengthen the study side it must be for a fixed budget at the expense of the "doing" side.

The Select Committee on Science and Technology raised objections to the system:

We do not doubt the competence of all concerned in stating their need for weapons, in evaluating the various proposals and requirements which emerge, in preparing specifications and finally in producing what is ordered. But the choice of which defence project to develop

appears to be a process of gradual and unconscious approach to a consensus of what should be done by filtering out the unpopular projects. It does not look like an open and conscious process in which financial and time-scale constraints are set against alternative forms of weapon system, force structure and strategy, and against a clearly understood background of defence and foreign policy objectives. The background of objectives appears to be the least stable element in the whole system. It must be very difficult for the people on whom the consensus depends to know what objectives they are working towards.

and proposed their solution:

We recommend that the future planning of defence research and development should be carried out by using a very wide range of the techniques known as strategic studies, force structure and weapon system studies and operational analysis. We further recommend that the Defence Operational Analysis Establishment should be expanded and provided with the necessary facilities to pursue these studies.

Operational Analysis is an extremely powerful weapon in the analysis of past or current operations and can also analyse future possibilities, assuming these can be put in a numeric or at least logical form. It can, of course, only present the input assumptions in a new form as Bertrand Russell claimed for mathematics.

The input assumptions are normally the product of experienced but human judgment, but as the Select Committee states:

The background of objectives appears to be the least stable element in the whole system. It must be very difficult for the people on whom the consensus depends to know what objectives they are working towards.

It is perhaps fortunate in real life that in many cases the material solution is not very sensitive to *the background of objectives*. This is the defence posture of the nation, a subject at present perhaps as much subject to emotional pressure as to cold, calculating and detached scientific logic.

It is of interest to look back with hindsight on the decisions which have been taken in the past decade. From this I believe that more upset to the naval R & D programme has been caused by bad cost estimation than by any changes in the military scene, the former of course reacts on the latter.

Management of the Programme

Once an item is approved as discussed above, it is the responsibility of the establishment Director to manage it. For complex projects, not research items, it is usual to carry out initially a Feasibility Study to determine possibilities, followed by one or more Project Definition Studies. Such studies have to go up the chain of command, approval being given before the next phase can be started. At the end of the Project Definition study, which may cost, say 10% of the total development, it is hoped that sufficient is known for accurate costs and times to be determined. Unfortunately this seldom turns out to be so. The usual management aids such as PERT, Milestone Charts etc., are used to aid the Project Leader, who has complete responsibility for his project.

The Project Leader is supported by his senior officers in a variety of ways. For example, the Director can and does review the project formally from time to time and in some instances the Project Leader's senior has a formal review every few months. The financial side of the larger projects is also scrutinised by the Under Secretary of the Department, responsible for finance.

The escalation of costs is not solely due to under-estimation; often the military requirements change during development and possibilities open up which the Naval Staff are anxious to exploit. In advanced work it is of course almost impossible to anticipate every technical difficulty; anyone who has worked in R & D knows that it is the unexpected which causes the difficulties and even the most experienced men cannot foresee every snag. If they were able to, the project might not be sufficiently ambitious.

Establishments in MOD(N) are organised on a Project Basis, although on the research side it is of necessity rather more on a techniques footing. Technical experts from the techniques side act as consultants to Projects and also ensure that the young are trained in the appropriate techniques.

At one time much of the Defence R & D work was done in Government establishments. The percentage done by contract in industry or at the universities varied considerably between departments, much of MOD(N)'s work being done intramurally. Of recent years, however, about half of the total R & D for the Navy has been undertaken on contract. The number

of Scientific Staff has decreased and continues to do so. It is strongly argued by some that development and production should be done in the same unit; if this is accepted it implies that development of electronics and weapons should be done in industry.

However, as the final responsibility for the spending of public money rests with the department it appears vital for Government establishments to carry out sufficient work to ensure that the staff are knowledgeable about their subjects and can manage affairs properly. Also Government establishments often have unique equipment and facilities so they are well equipped to undertake certain forms of basic research and also tests of final systems. It is also convenient that they do much of the assessment and analysis. Capital assets that exist at Government establishments are very substantial; moreover for some work they have been very carefully sited to allow certain types of experimental work.

Research items which are mainly done " in house " are closely controlled. As stated previously each item has to be justified to the Defence Research Committee. To get approval an explanation must be advanced as to the expected benefit from the research and the work broken down into detail showing the men and money involved and the expected time scale of the endeavour. This is usually known as " Management by Objectives ".

Each year the sponsor must demonstrate how well he has fulfilled his expectation and put forward his plan for the future. If he has explained fully, the expected benefit of the research item, the previous year, he is only called upon to update it.

It is customary in the Naval hardware establishments to arrange the organisation as shown on the diagram in Fig. 2.

The Director has a number of departments each of which is responsible for a group of Projects. Each Project, as has already been said, is managed by a Project Leader who has complete control of all aspects of the project. In the diagram the Project Leader is shown, assisted by a manager who is concerned with the business aspects, programme planning etc., and also by men knowledgeable in the various techniques used in the project. Each is sustained by experts in the research area working on the appropriate field as approved for the research programme. A big project may have several men concerned in each technique's field, especially in an area in which the contractor is weak. For a small project one man may have to cover many techniques.

It has been found in practice that a team of 100 professional staff at the development contractor need, say, 10 men in the establishment, provided the 10 are adequately sustained by experts in the research or techniques area. For smaller projects the ratio of 10/1 cannot be sus-

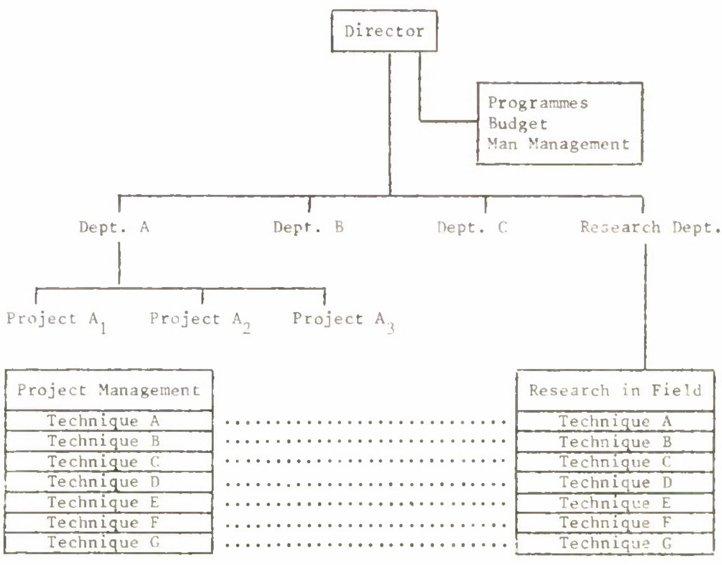


FIG. 2. Project organisation flow diagram.

tained as the paper work and business activities do not increase linearly with the size of the project. It will be appreciated that the cost of the 10 "in house" men needed for 100 contractors staff does not add much to the cost and if they only smooth the passage of the project slightly they justify their keep. It must not be forgotten however that in many, but not necessarily all, areas of defence work, the real knowledge lies in the establishments not at the contractors. The "in house" men are also very much occupied on the interface relationships between one project and another. A warship contains weapons and systems arising from many projects, the interface problems of which can thus be very formidable.

The Director usually has a planning and budgeting staff to assist him and to maintain records, diagrams, charts, etc., to show the progress of projects and to control expenditure etc.

There have to be fairly large support resources, especially in the underwater field, where underwater ranges and testing facilities are required as well as special research ships.

Under present conditions in establishments responsible for development, the total cost of development contracts exceeds the running costs of the establishments, including all pay, salaries, etc. Over the Navy Department as a whole more R & D work is carried out by contractors working under contract than in government establishments.

An idealised development establishment letting contracts worth £10^7 could be manned as follows by professional staff: (QSEs in one jargon)

Directing Staff	10
Assessment and Analysis	20
Management of Common Services and Trial Facilities	50
Projects	150
Research and Techniques	100
Post Design	50
Total	380

The intramural cost if it were 10K per man is £$3{\cdot}8 \times 10^7$.

It must of course be remembered that if the work has to be done it must be done somewhere, either in an establishment or at a contractors. The minimum overall cost is achieved when the best solution is found.

Man Management

Much of the R & D is carried out by members of the Scientific Classes (Scientific Officer, Experimental Officer and Scientific Assistant) and for simplicity my remarks will be confined to these classes. The importance of the proper management of men needs no overstressing.

All permanent members of the class must be accepted by the Civil Service Commission. They have to serve for a probationary period of two years. This is taken seriously as once a man is accepted into the Civil Service he tends to make it his career. Recruitment normally stops at around the age of 30.

Usually in Government Departments the work load is assessed and x_1 officers of y_1 grade, x_2 officers of y_2 grade etc., are allowed. An officer of a lower grade can only be promoted to a higher grade when a vacancy exists.

From time to time the situation as regards posts is re-examined to determine whether changes are necessary e.g. to see whether an additional clerical officer is needed, whether a post is any longer required.

For the R & D work there is, however, a continual change in the effort employed on Projects and Directors have freedom to deploy scientific staff as they wish. They must however take care that the costs of individual projects do not increase. In addition, subject to certain limitations, up to the rank of PSO a man is promoted when he is deemed fit. Above PSO there are defined jobs or posts and a man can only be promoted into a vacancy.

Staff in Ministry of Defence are managed centrally but there is still, however, a strong individual Service influence.

As previously mentioned, Directors are given a quota of staff and are fairly free to deploy them as they deem proper.

However, very considerable attention careerwise is given by central management, for Ministry of Defence as a whole, to each man. Every year each man has to outline his work for the past year and remark on his achievements and hopes. His senior officer remarks on the man's ability on a number of headings and gives his opinion on the man's suitability for higher positions. Each man usually has an interview each year to discuss his career with a senior officer of his establishment. Finally, his establishment Head has to report how far he expects the man to go in the service.

When a man is considered suitable for promotion he is seen by a Ministry of Defence board and, if his record is good and is sustained by his performance at the interview, he is recommended for promotion subject to approval by a panel and in the case of Navy Department by the Head of the Royal Naval Scientific Service. Interviews last about three-quarters of an hour and every effort is made to give the man ample opportunity to demonstrate his abilities.

Departmental Class to Class promotions which will cease when Fulton is implemented and classes disappear require the presence of a member from the Civil Service Commission on the board.

Officers who are considered likely to attain fairly senior appointments are given the opportunity of broadening their experience by moving around within the Navy Department. They would normally serve for a period in Headquarters but might serve outside the Department on exchange schemes or be attached to an Embassy. They are also sent on a variety of courses, including business management.

Senior Principal Scientific Officer posts are advertised inside the Government service and applications invited. Selection is by merit and this procedure usually involves interviewing the candidates.

Above SPSO posts the procedure is somewhat different in that Directors, Chief Scientists etc., are asked to nominate candidates with the Department owning the post making the final selection.

Close contact is maintained at all times with representatives chosen by the staff. The Staff Side can and do urge that certain individuals not put forward by their Establishments should appear before interview boards.

Although the procedures involve a good deal of paper work and absorb the time of a lot of senior members, the staff are remarkably content with a system which they reckon to be fair. In this regard the procedures on the scientific side compare very favourably with those in the rest of the Civil Service.

There are some officers who by inclination or aptitude wish to remain on scientific work and are not suited nor wish to fill SPSO or other senior posts which normally call for considerable managerial activity. Their careers are looked after by considering promotion on individual merit to SPSO or above. The Civil Service Commissioners handle individual merit promotions and the standards set are high, corresponding for senior promotions to that expected for a Professor.

There are also panels in MOD(N) which examine officers' careers and do their best to give the individual every opportunity of improving his value to the Service and to himself.

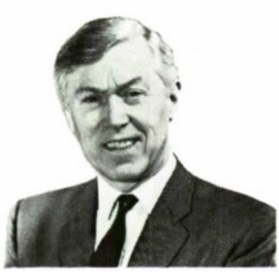
There is one problem in the overall management that is possibly peculiar to the Civil Service. Recruiting in the main takes place below 30 and there is little normal exodus of men over, say, 35 because of pension arrangements and other limitations. This would not be of importance in a static society since recruiting can offset those retiring and others who fall by the wayside. However, there are occasions like the last war and the Korean crisis when "the Defence side" was greatly boosted in numbers. This "bubble in the pipe" causes unfortunate age number distributions which are especially serious when the age of people in the "bubble" nears retiring age: an ageing population is not normally regarded as ideal for the production of new ideas. Expansion is always fairly easy by expanding recruitment, but a reduction in numbers is difficult given present Civil Service procedures. A contracting service can mean an ageing service; an adequate number of young men is needed to provide new inspiration and ensure that the older men are kept on their toes. With the stimulus of the young it is surprising how the whole outlook becomes more alive, a phenomenon probably well known in all long established laboratories.

WELDING ON WET PRIMARY CIRCUIT SYSTEMS TYPE 304 STAINLESS STEEL

Parameters Controlling Root Oxidation

F. Tribe, R.N.S.S. and
W. Tregunno, R.N.S.S.
Central Dockyard Laboratory, Chatham

Fred Tribe joined the Admiralty Fuel Experimental Station (now (AMEE) in 1949 as a Scientific Assistant, transferring to the Central Metallurgical Laboratory (now CDA) in 1952. After four years' service in Malta he returned to CDL until 1963 and then spent a further four-year period at the Devonport Dockyard Laboratory. In 1967 he was promoted SXO and took charge of the Dockyard Laboratory at Chatham.



Bill Tregunno was a member of the Engineer in Chief's Staff during the war, joining the RNSS as a Senior Scientific Assistant at Chatham in 1949 via the Ministry of Works. He too had a period of service as XO in Malta from 1957 - 1960 after which he joined the Dock-Laboratory at Chatham.

Abstract

It has been shown that water present in the vapour phase in purge gas will not cause significant oxidation of weld root runs made in Type 304 Steel. Gross oxidation will result if minimal quantities of water are present as liquid. Wet purge gas can be effectively dried (to dew point −20°C) by means of an additional freeze seal unit. The results are discussed and recommendations made to modify existing weld procedures.

Introduction

The renewal of certain spray line valves in H.M.S. *Warspite* during an intermediate docking at Chatham in 1969 involved butt welding of associated Type 304 austenitic stainless steel pipework. Freeze seals were applied and the first valve removed, its replacement fitted into position and the system purged with dry argon (moisture content <10 p.p.m.) until the oxygen concentration in the exhaust purge gas was $<1\%$.

The resulting weld root runs, made with E.B. consumable inserts, were rejected by radiographic assessment and the valve cut out. Visual examination of the weld showed excessive bore protrusion and associated gross oxidation.

High purity argon containing <10 p.p.m. moisture had been used both as arc shield and backing gas and the oxygen concentration of the latter controlled below 1%; it seemed reasonable to suppose, therefore, that the oxidation observed had resulted from residual moisture in the system, transported by the purge gas.

The system had to be purged for many hours before suitable conditions for re-welding were established.

The experience at Chatham was found to be not unique; it transpired that similar difficulties had been reported elsewhere when welding on pipe systems containing residual moisture.

It was decided, therefore, to promote an experimental programme designed to establish an empirical relationship between the moisture content of exhaust purge gas and the resulting degree of weld root oxidation. The project received MOD(N) endorsement in DGD & M Letter N/DM2751/69 dated 26-6-69.

Following completion of the initial trials, the programme was extended in an attempt to create a controlled environment suitable for welding but eliminating the need for prolonged and costly purging.

Experimentation Water vapour contents of cylinders of argon gas were determined by MEECO meter incorporating a phosphorus pentoxide cell. The gas was led to the cell *via* a low internal volume, reduction valve and 1/16 in. diameter stainless steel tubing. Flow rates were controlled by a flow meter fitted on the exhaust side of the cell. No non-metallic materials came into contact with the gas on the input side of the cell and thus the possibility of sample contamination was minimised.

Measurements were carried out at a nominal pressure of 10 bars which was known to produce a rapid cell response[1].

Oxygen was determined by an Englehard Mk. II meter utilising a Hersch electrolytic cell in conjunction with a similar reduction valve and connecting tubing .

The measurement of oxygen and water vapour in purge gas was determined by Servomex Analyser Typ. DCL 101 Mk. II and Moisture Control and Measurement hygrometer Series 1000 respectively. The latter instrument indicated water vapour content or percentage relative humidity by recording changes in the electrical conductivity of an alumina coated sensor, and was calibrated using a series of saturated solutions of metal salts.

Purge gas of the required water vapour content was produced by mixing dry and saturated argon in the appropriate quantities, and monitoring the resulting moisture content with the latter instrument. Oxygen concentrations were established by controlled additions of high purity oyxgen.

Results of Welding Trials—Phase I

High purity argon containing less than 10 p.p.m. of oxygen and water vapour was used throughout as the arc shielding gas; details of other welding conditions are given in appendix 1.

The first series of welds were made with argon backing containing less than 10 p.p.m. of water vapour but with increasing amounts of oxygen, up to 15%. The nature of the oxide layer, illustrated in Figs. 1 and 2, remained a thin, tightly adherent film for oxygen concentration of up to 5%; above this figure the film thickened appreciably and oxide particles formed which could be detached without undue difficulty.

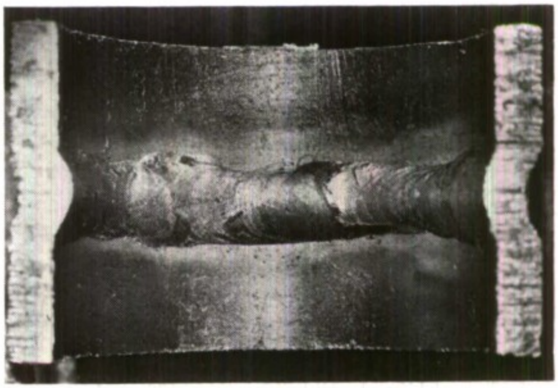


FIG. 1. Moisture <10 ppm Oxygen <0·1% × 5.

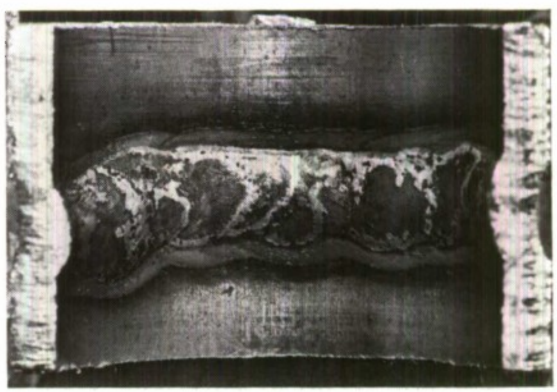


FIG. 2. Moisture <10 ppm Oxygen 5% × 5.

The second series of welds, were made with argon backing containing less than 0·1% of oxygen but with increasing amounts of water vapour, up to 21,000 p.p.m. Fig. 3. This figure represented a value of 99% relative humidity at the prevailing temperature.

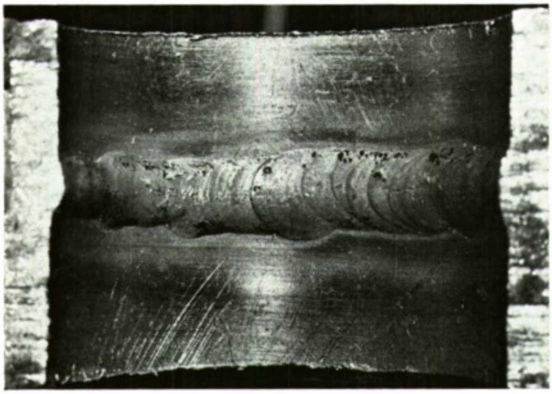


FIG. 3. Moisture 21000 ppm Oxygen <0·1% × 5.

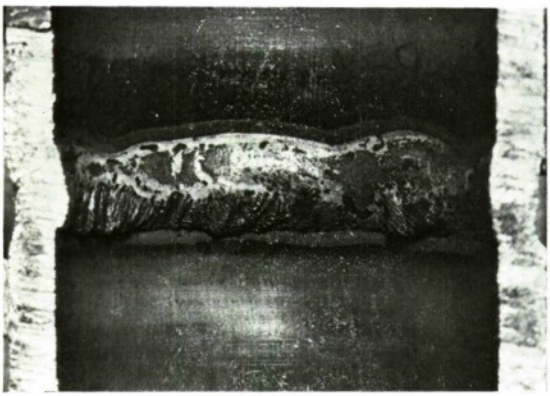


FIG. 4. Moisture 10000 ppm Oxygen 5% × 5.

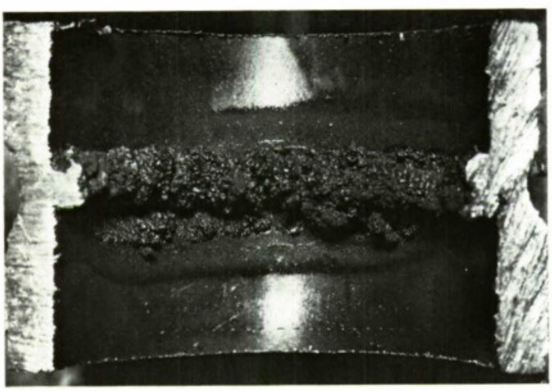


FIG. 5. Moisture 21000 ppm Oxygen <0·1% plus × 5 water. 0·5 ml/min.

No significant change in the oxide layer from that on the control specimen could be detected in any of these trials.

The third and fourth series of welds were made with argon backing containing constant levels of water vapour, 5,000 p.p.m. and 10,000 p.p.m. respectively, each series with increasing oxygen contents. The results, illustrated in Fig. 4, were similar to those obtained in the earlier trials and confirmed that root oxidation became significant only when the concentration of oxygen reached 5% and were virtually independent of water vapour content.

At no time during the above trials had it been possible to reproduce the degree of root oxidation observed in service, merely by introducing water vapour into oyxgen free (<1%) argon purge gas. It was decided, therefore, to trickle water into the pipe at a controlled rate whilst welding was in progress.

The result, which is illustrated in Fig. 5 was both immediate and dramatic; gross oxide formed over the entire root run and this effect was reproduced on every occasion that water was introduced, irrespective of the quantity involved.

Following completion of the root runs, the specimens were blanked off at both ends and forwarded, without obvious identification, for radiographic examination. It soon became apparent that a thin uniform oxide film was not detectable by this process and that positive identification of oxide was only possible when the formation was gross.

Discussion

The results of the above trials had shown that gross root oxidation of welds made with oxygen free (<1%) argon backing was caused by the presence of water and not water vapour.

It is suggested that the reason for this may be a function of reaction kinetics, that water vapour in the purge gas flow is not in contact with the weld for sufficient time for catalytic dissociation to occur, with consequent oxidation of the metal. On the other hand, however, water droplets could be trapped in the capilliary formed by the unfused consumable insert and be dissociated by the energy of the welding arc.

The problem could now be regarded as the need to prevent water droplets being transported by the backing gas and deposited in the weld area, and was one made greater by the complexity of primary circuits, which often precluded total drainage of particular branches.

Advantage would be gained by keeping purge paths as short as possible and also by blowing through with high pressure nitrogen in an attempt to displace residual pockets of water.

Further drying could then be achieved by the formerly used expedient of prolonged purging, whereby the purge gas acted as drying agent.

The method is, however, both wasteful in time and expensive in the quantity of gas used and suffered from the further limitation that, even after many hours purging, no assurance could be given that water droplets would not be deposited whilst root runs were being made.

It was decided, therefore, to examine the possibility of removing entrained water by passing the purge gas through a length of the pipe which had been cooled to a sub zero temperature.

Welding Trials—Phase II

A freeze seal refrigeration unit was fitted to the pipe between the weld and the purge gas inlet and a number of tests were made under various conditions of water and water vapour contamination, both with and without the cold zone in operation.

The unit was effective in freezing out water flowing at up to 0·5 ml/minute, a thin continuous trickle, but above this flow rate, water built up behind an ice dam and eventually overflowed onto the weld area.

Tests were carried out with the pipe in a number of positions between the vertical and the near horizontal and similar results were obtained. It was also found that the cold trap was remarkably effective in reducing the water vapour content of the gas.

The success of the technique is shown in Figs. 5 and 6 which show two root runs, each made under the same conditions of water plus water vapour contamination of the backing gas but with a cold trap fitted into the pipework of the latter weld.

Final welding trials were completed to determine the effect of subsequent "fill in" runs upon the oxide film of weld roots, the film resulting from the use of a saturated argon backing remained acceptable and could not be detected by radiographic examination. It was apparent, however, that an improvement was obtained from the use of a cold trap.

Metallographic Examination

Macro and micro sections were taken through a number of specimens and the oxide film examined. The effectiveness of the cold trap is again demonstrated in Figs. 7 and 8 which show sections taken from the welds illustrated in Figs. 5 and 6.

In no case did the oxide formation penetrate the weld bead but was present only as a surface effect. Fig. 7.

FIG. 6. As FIG. 5 with cold trap in circuit × 5.

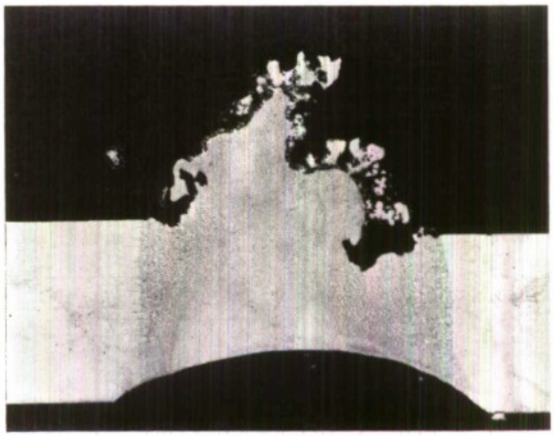


FIG. 7. Macro of FIG. 5 as welded × 15.

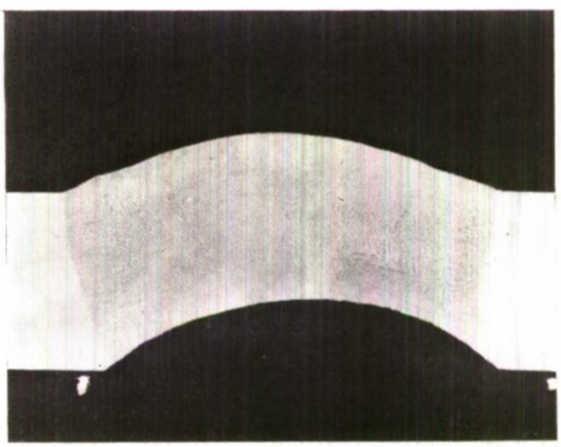


FIG. 8. Macro section of FIG. 6 × 15.

Conclusions

1. Water vapour in purge gases will not cause significant root run oxidation in Type 304 austenitic stainless steel pipe welds.
2. Minimal amounts of water in droplet form will cause gross bore surface oxidation of root runs.
3. The formation of a cold zone in the pipe by a freeze seal unit placed upstream of the weld, will effectively dry the purge gas to a dew point of approximately $-20°C$, for all concentrations of water vapour plus water flowing at $<0{\cdot}5$ ml./min.
4. Slight uniform oxidation is not revealed by radiography and even if just perceptable on a radiograph, is actually present in gross form.
5. The use of high purity argon for purging pipe lines cannot be justified and instructions should be issued to use uncertified gas of commercial quality.

Recommended Pre-Weld Procedure

1. Select purge path and apply freeze seal units in normal manner. Purge paths should be as short as possible to minimise moisture pick up.
2. Remove component/s and drain residual water.
3. Blast through system with high pressure, commercial quality nitrogen to remove pockets of water.
4. (i) Cut stub ends of new unit to required length. Check bore sizes of new unit and existing pipe work making necessary adjustments such that the bore of the latter is ·0005 in. to ·005 in. greater than the stub ends of the former. Tack consumable inserts to stub ends of new unit. The greater part of this work and certainly the tack welding should preferably be carried out in the shop.

   (ii) Fit a further freeze seal unit upstream of the welds on the drained portion of the system such that a sub zero temperature zone may be formed (Hereinafter called the cold trap).
   Careful consideration should be given to the position of this unit such that it lies
   - (a) between the first weld and any secondary branches and, after compliance with (a)
   - (b) on a horizontal length of the system.
   - (c) as far away from the weld as possible to allow the temperature of the cooled purge gas to rise.
5. When new unit is ready in all respects
   - (i) repeat nitrogen blast as in 3
   - (ii) operate cold trap
   - (iii) commence argon (commercial quality) purge
6. Purge for 15 minutes before clamping new unit into position.
7. Continue purging until oxygen content of exhaust gas is below 1% weld root runs.

Complete welds by normal procedures.

It is important that the cold trap has been effective for at least 15 minutes before the new unit is clamped into position and is thereafter maintained throughout the entire welding operation.

Acknowledgement

The welding and radiography of the test welds were carried out by members of the Production Department and the ready cooperation of their responsible officers is gratefully acknowledged.

APPENDIX

Standard Welding Conditions

Power Source	B.O.C.—A.M.R. 250
Voltage	20 Volts D.C.
Current	60 amps.
Polarity	Electrode negative
Arc Shield	High Purity Argon Moisture, Oxygen <10 p.p.m. 18 cu.ft./hr.
Backing	Commercial Argon 4 cu.ft./hr.

Reference

[1] Chemical Inspectorate Memorandum No. 202. "The Determination of Moisture in Permanent Gases". N. A. Hodgson, *et al.*

THE END OF THE IMPERIAL DEFENCE COLLEGE

E. J. Risness, M.A., Ph.D., M.I.E.E., i.d.c., p.s.c. R.N.S.S.
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Eric John Risness was educated at Stratford Grammar School, London, and Corpus Christi College, Cambridge. After taking a Ph.D. degree in Nuclear Physics ("A Resonant Cavity Electron Accelerator") he joined the R.N.S.S. in 1954 at ARL, Teddington. He worked on the application of digital techniques to passive sonar processing problems until 1961, when he moved to AUWE to work on the application of digital computer techniques to active sonar detection and tracking. In 1967 he took over the Sonar Techniques Research and A/S Training Division. After a year at the Imperial Defence College he returned to AUWE in charge of the Underwater Weapons Research Division.

On Thursday, January 14th, 1971 the Imperial Defence College, founded by Sir Winston Churchill and others in 1927, closed its doors for the last time. Two weeks later the first batch of students at the new Royal College of Defence Studies started their 12-month course in the same building.

Future historians of British and Empire-Commonwealth defence organisations will have to decide to what extent this change of name marks the end of an era, or whether the era for which the IDC was designed had ended long ago—perhaps even at the end of the Second World War. Nevertheless it may be an appropriate moment for one who was fortunate enough to attend the last IDC course to give some impressions of it, and in particular of the way it appears to be orientating itself for the future; since although it was the last IDC course rather than the first RCDS course, in fact many of the changes planned for the course (other than the change of name) took place in 1970.

A word or two about the Course as a whole to set the scene. The Imperial Defence College (and now the RCDS) is at Seaford House, in Belgrave Square (behind Buckingham Palace). It is designed to give officers of the rank of brigadier, senior captain RN, or rough equivalent (military and civilian) a broad background in matters related to defence, to fit them for higher posts in the defence field. Seventy or 80 students attend the course, roughly half from the UK and half from overseas. About 30% of the students are civilian—diplomats, administrative civil servants, *etc.* with a maximum of two scientists(!). The course includes lectures, discussions, syndicate and individual work, and visits both at home and abroad, the highlight of the course being an overseas tour lasting four weeks. (Those who remember a previous article on the IDC in this Journal[1] will note that these broad features have not changed very much over the past decade.)

In the 1970 Statement on the Defence Estimates it was announced that "Major changes have been made, or will shortly be introduced, in the composition, teaching methods and syllabus of the Imperial Defence College . . . At the IDC, where the Hon. Alastair Buchan, CBE, is serving as Commandant for 1970 and 1971, senior officers and officials study problems of strategy, international relations and major issues of defence policy. Students from other European countries are for the first time joining those from the Commonwealth and the United States to make up a student body drawn from 18 nations, and the course provides for study of European problems in greater depth than in the past. The College will be re-named the Royal College of Defence Studies in 1971."

Alastair Buchan, who prior to his appointment to the IDC was head of the Institute of Strategic Studies, is only the second civilian to take over as Commandant of the College, the post normally having been held by a four-star General or equivalent from each Service in rotation. Since the previous civilian was Sir Robert Scott, a Chief Commissioner of Police, whereas Mr. Buchan's career has been more in the "academic" or university tradition, his appointment represented an even greater break with tradition than would appear at first sight, and he has in fact re-modelled the course and curriculum very significantly. His wide acquaintance with public figures (political and otherwise) has resulted in many distinguished men lecturing the Course for the first time—though it must be admitted that not all the speakers brought in from the academic side lived up to their reputations! On the other hand, his introduction of the concept that every student should write a 10,000-word "thesis" on some subject not too closely associated with his previous experience under the guidance of an external "tutorial" adviser and with an eye to publication in an appropriate journal, was not too favourably received, as one might expect! It had the (intended) result that students on average worked harder than before. (This is not solely a personal and biased opinion, but is backed by independent statistics on how often the keen golfers managed to play golf compared with previous years!) But the idea that a majority of the theses would be worthy of publication seems to have not been realised, largely because of the fact that most students were breaking unfamiliar ground, the result being self-education more than the production of original ideas.

The most significant innovation, however, was the introduction of European students for the first time; two each from West Germany and Italy, one each from Norway, the Netherlands, Belgium and Turkey—none from France, but two are attending in 1971. This gave greater point to most of the discussion, not only to those about Europe but also to those set outside Europe. It was noticeable, for example, how the question of a continued British presence in the Far East was put into perspective by the presence of other European representatives with a more detached view of the situation. Of course the general attitude to European problems was significantly influenced by their presence, and, though many students would have personal reservations about it, this was probably the first IDC year that by and large assumed that Britain was about to go into Europe and seriously considered the implications of this historic step.

The course was organised into four terms. The first was devoted broadly to the balance of power in the world, and included studies of the super-powers, Britain in relation to them, the nuclear deterrent and so on. The second term was concerned with various technological and social aspects of modern society, including such diverse topics as economics, science and technology, business management techniques, industrial relations, crime and violence, etc. After the overseas tours in July, and leave in August, we returned to study the developing world for the third term. The fourth and culminating term was devoted to Europe, its problems and its future.

Apart from our main overseas tour, to which I will return later, we had visits to all three Services and an industrial tour, plus one or two minor visits. The Naval visit was to Portsmouth, with talks by Admiral Frewin, C.-in-C. Home Fleet, and others, and a day aboard H.M.S. *Eagle* watching flying displays and looking at equipment.On a later occasion we visited R.A.F. stations in Lincolnshire including among other things, another flying display. The highlight of this visit for me was to fly in a two-seater Jet Provost trainer and take over the controls in the air. Our Army visit was to the Rhine Army in West Germany and was combined with visits to NATO, SHAPE and Berlin (including a trip into East Berlin). Again the experience of driving a Chieftain tank added to the occasion. On our industrial visit, I was in a party which visited the North East (Newcastle and the Durham area) for a week, including chemical (ICI)

and engineering concerns, a shipyard, a coal mine and a brewery.

But the highlight of the whole course was undoubtedly our overseas tour in July. The course was divided into six groups for these tours. Two groups went to the Far East, starting at Singapore and Malaysia; one of them went on to Japan, and the other to Australia and New Zealand. Other groups went to the United States and Canada, to Scandinavia, and to Western Europe.

I was lucky enough to get on what turned out to be undoubtedly the best tour of all, to the Eastern Mediterranean. Starting at Naples (with briefings from the NATO command there) we visited Yugoslavia, Roumania, Cyprus, Israel, Iran, Turkey and returned *via* Malta. The six main countries fall into three groups, two Communist countries, two countries with racial/national problems (internal or external) that have broken out into fighting more than once in recent years, and two countries bordering on U.S.S.R. with Western-looking alliances (NATO and CENTO).

The two Communist countries were extremely interesting, though in different ways. In Yugoslavia the main interest was to see how a country which still regards itself as Communist from the ideological and political point of view (the Communist party is still the only political party) is nevertheless moving well away from orthodox Communism in the economic field. A real attempt is being made to decentralise the control of industry and put it in the hands of the workers within the industry. Furthermore the supply of goods is controlled by the market for them as in any capitalist country, rather than by targets fixed by the state. The Yugoslav experiments in this field are, I feel, of the utmost importance in showing whether an intermediate way can be found between capitalist and communist systems. One can only hope they will get a fair trial and not be upset by other problems inside or outside the country.

Roumania gave us quite a different impression. Although she has made a great show of being independent of the U.S.S.R.—and demonstrates it, *inter alia,* by inviting Western groups like the IDC to visit—yet she is still an orthodox Communist country, one might almost say a Stalinist country. The atmosphere of a Police State, detectable to some extent in Yugoslavia, was much more noticeable and oppressive. We spent only two days there, and the Roumanian liaison officers went out of their way to look after us and create a favourable impression, but nevertheless we were very glad to get away at the end. (In any other country on the tour I would have been happy for the aircraft to break down for a week !). To my mind a visit to a country such as Roumania is a salutary reminder, for those of us who get fed up with the obvious problems in our own society, that there are social structures far worse than our own, of which we must continue to beware.

In Cyprus we had the interesting experience of meeting President Makarios and then immediately crossing the "cease fire" line to talk to the Turkish Vice-President Dr. Kutchuk. The two men have not, I believe, met each other since fighting broke out in 1963. Although there has been little violence in Cyprus for the past seven years the conflict between Greeks and Turks seemed to be no nearer a solution—a grim reminder that the Northern Ireland problem also will not be solved simply by stopping the fighting.

For me the highlight of our tour was our four days in Israel, a country of great historical interest as well as topical problems. The Israelis were keen to put over their viewpoint on their conflict with the Arabs, and we met a number of distinguished people from the Prime Minister, Mrs. Meir, downwards. We had a day in Jerusalem, a day going to and from the Syrian border, and a day at operating army and air force bases. One point of interest was that the maintenance of sophisticated aircraft and weapons, which was modelled on British maintenance organisation and methods, seemed to work well under war conditions (the Israelis were flying sorties over the Suez Canal while we were there). In general, we came away with an improved understanding of the Israeli viewpoint, but at the same time concerned that they showed no sign of being psychologically prepared to make the sort of concessions they must make if a settlement is to be reached.

Like Israel, Iran and Turkey were of historical and architectural interest, but their major current problems were their relations with the U.S.S.R. and their economic development. Teheran was, to my surprise, the biggest city we visited on the whole tour ($3\frac{1}{2}$ million people) and with the fastest and most dangerous traffic. In Turkey I went down at last with Eastern "tummy trouble," luckily near the end of the tour.

The main impression we came back with was to reinforce our view that the area we call the Middle East, and which to the U.S.S.R. is the Near South, is a region of much cultural and

racial complexity, of great importance to the West because of its oil supplies, but where the Russians are keen to extend their influence whenever opportunity offers. How to counter this increasing influence is quite another question, but it was interesting to see a predominently military group of people in general take the view that the Russian influence could not be solely, or even primarily, countered by the display of Western *military* strength alone.

This leads on naturally to consider what points of interest arose from the course as a whole. Every student would have different views on this, of course. For my part I would like to set down one or two that have struck me during the year. They are somewhat disconnected, not of equal importance, and many are hardly new. But they are set down in the hope of provoking thought.

The first concerns possible scenarios for future wars involving the Western powers in general and the United Kingdom in particular. I started the year hoping that the course would shed some light on this question, so crucial to Defence planning. But at the end of the course the only specific scenario I could envisage was the one we all knew about before; namely, battle on the central front in Europe where strong standing armies are deployed on both sides. But the general feeling was that war in Central Europe, though highly dangerous to the West, was not at all likely to occur (given the maintenance of adequate conventional forces as a deterrent) and that actions elsewhere were more likely during the next 10 or 20 years. My view is that such conflicts are not likely to involve a direct confrontation of the two superpowers, or even of the U.S.S.R. with one or more Western European countries. Instead they may involve one power group directly and the other indirectly (as in Vietnam) or else both indirectly (as in the Arab/Israeli conflict—though the U.S.S.R. is almost directly involved by now). In other words, Britain is not likely to find herself alone (or with allies) directly facing the U.S.S.R., but is more likely to be facing a country or group of countries which have Communist support. The most likely (or perhaps I should say the least unlikely) reasons for conflict involving the U.K. seem to me to be, firstly, the vital need of the West Europeans for oil from North African and Middle East countries, and secondly (less likely and more remote in time) the possibility of racially-based conflict somewhere in the southern half of Africa. It is noteworthy that both of these scenarios imply an important role for the Royal Navy, but this role is not likely to be the defence of Western trade against the full weight of Soviet sea power, as so often appears to be the assumption in Naval planning.

My second point concerns our approach to defence planning. Here in the U.K. increased financial stringency coupled with an emphasis on cost-effectiveness and business management techniques have meant that our defence planning is obsessed with spending a fixed sum of money per year in the most cost effective way, with apparently no contingency planning if the defence expenditure and consequently the size and strength of the Armed Forces had to be expanded suddenly to meet a situation of rising world tension and perhaps of war. Contingency planning for this could imply proportionately more expenditure on " long lead " items of research and development, and certain aspects of production, than are needed by the current Armed Forces, and if tension did not rise and the defence expenditure remained constant some of these support items would not be used. Nevertheless it can be argued that in an era when world tension is low and defence expenditure has been cut back (as at present) it is important to be sure that it can build up again suddenly if required. This point is argued at more length in a companion article[2].

A third point relates to the concept of "graduated response." Ever since nuclear weapons became available in quantity countries have distinguished between conventional and nuclear war and have tried to confine wars to a certain level of destructiveness and not let them " escalate " to a higher level. But we have not gone on to apply this within the gamut of conventional war. In fact many of our conventional weapons may be more destructive than one would wish in many situations, so that the ability to respond to the situation in a politically acceptable way is reduced. For example, it may be politically desirable to stop or incapacitate ships without loss of life, on occasions such as the Rhodesia blockage or the 1962 Cuban crisis. Ships and submarines armed with weapons aimed solely at *sinking* ships are of very little use in these situations and we may need to pay more attention to the development of limited capability weapons.

Finally, a point arising out of the whole concept of a course aimed at a broadening of one's general education at a comparatively late stage in one's career. This sort of course would benefit a much wider range of people than the few who

are privileged enough to take it, and reminds one of the whole question of further education of adults during their careers. It seems absurd, when one stops to consider it, that society educates and trains its citizens more or less full time up to their late teens or early twenties, then expects them to work for 40 years almost entirely on the basis of this early education. Technological advances are changing society so rapidly that employment patterns at all levels change in a 20 year period and technical education becomes out of date in the same time scale. In my view, instead of continually increasing the amount of early education (by raising the school leaving age, increasing the number of university places, and so on) we should consider spending this money and effort on a flexible system of adult education to encourage people at all levels to develop their talents and become more responsive to the changing pattern of society.

As these points no doubt illustrate, the IDC is not a "think tank" for startlingly original ideas. Rather it is an opportunity to draw back from one's day-to-day problems and look at Defence in a wider perspective—political, economic, technological and social. This is particularly important in an era when Britain's role in the world is changing rapidly, and as the future pattern of Defence becomes more and more difficult to visualise. If a year at the IDC or RCDS enables students to view their problems from the standpoint of the '70s, rather than from some earlier and perhaps more glorious era, then the course, though expensive in time and money, is well justified.

REFERENCES

(1) Pout, H. W. "The Imperial Defence College—A Personal Impression." *J.R.N.S.S.*, **15**, p.142. 1960.

(2) Risness, E. J. "The Dynamics of Defence Planning." *J.R.N.S.S.*, **26**, No. 5.

The need to ensure that explosive weapons attacks against ships of the Royal Navy cause the minimum of operational damage demands that weapons effects can be predicted accurately and the necessary protection measures can be developed and effectively assessed.

To yield the basic data for the development of response prediction theories and their proof and to evaluate protective measures the Naval Construction Research Establishment, Dunfermline, which is the principal MOD(N) Laboratory for this area of research, is currently conducting a series of explosion trials against the ex-destroyer *Scorpion* in the River Forth.

BOUNDARY LAYER ADDITIVES TO REDUCE SHIP RESISTANCE

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Pipes, flat plates and submerged bodies have been used to investigate the phenomenon whereby up to 50 per cent reduction in frictional resistance can be achieved by using boundary layer additives in very dilute concentrations. Various theories have been advanced about the physical mechanism involved. Among results obtained with ship models, AEW reduced the frictional resistance of a frigate form some 20 - 30 per cent by continuously injecting polymer solution into the boundary layer to produce a nominal concentration of 10 wppm. AEW and AML then carried out a full scale trial in a coastal minesweeper using equipment for continuously preparing solutions of Polyox WSR301 and making provision for boundary layer sampling. The fuel consumption of the CMS was reduced by up to 17 per cent at nine knots in spite of the Polyox being unevenly distributed in the boundary layer, but the result was grossly uneconomical in terms of current prices of Polyox and diesel oil. Even when employing an injection technique of greatly increased efficiency in a large ship such as a supertanker or containership, there seems little prospect of utilising boundary layer additives for profit until the cost of additive materials has been drastically reduced from present day levels.

Introduction

Interest has been shown for some time in the possible use of polymer solutions for reducing the drag of surface ships and submarines. Since most of the research work reported so far has been concerned with tests on pipes, flat plates and totally immersed bodies, AEW and AML joined forces to investigate whether a useful effect could be obtained in a surface ship. The main purpose of this article is to describe a full scale trial in which polymer solutions were pumped into the ship's boundary layer. Before describing the trial and the work carried out at AEW and AML which led up to it, it is of value to discuss the phenomenon responsible for the resistance reduction, known as the Toms Phenomenon, and this will be done by reviewing briefly earlier work documenting the subject and attempting to explain the physical process involved.

The remarkable reduction in hydraulic resistance caused by small concentrations of certain polymers dissolved in liquids was first reported by Toms[1] and has subsequently been named after him[2]. The magnitude of the phenomenon can best be illustrated by the fact that the turbulent frictional resistance of water flowing through a pipe can be reduced by at least 50 per cent when only 10 weight parts per million (wppm) of one of a variety of polymers is dissolved in the water. It is because such a large effect can be obtained at such a low concentration that the interest of so many workers has been engaged in measuring, explaining and attempting to apply the phenomenon.

This article is a condensed version of a paper read at a meeting of R.I.N.A. in London, 1970.

Types of polymer which reduce hydraulic resistance in water have the following properties:

(i) high molecular weight, typically about 10^6;

(ii) a long unbranched molecular configuration;

(iii) are readily soluble in water.

Synthetic polymers with these properties are polyethylene oxide (for example Polyox Water Soluble Resins) and polyacrylamides (for example Separans). Naturally occurring polymers are guar gum[3, 4], DNA[5], and several polysaccharides which are present in certain marine and fresh water organisms[6-8]. Suspensions of long thin fibres have also been found to be effective, but at concentrations much higher than for dissolved polymers[9]. The phenomenon is not limited to water systems and has been observed with several polymers dissolved in other solvents[1, 10, 11] and has been utilised to reduce the frictional loss in oil pipelines[13].

The majority of investigations of the phenomenon have, perhaps inevitably, studied pipe flow. There are numerous references to work carried out with smooth pipes[3, 10, 11, 14-19], but comparatively little work has been done with rough pipes[20, 21] and curved pipes[22, 23]. Investigations of flow around bodies such as spheres[24-26], submerged flat plates[27-29], cylinders[30-32], cones and discs[33] have also been reported, and are clearly of more value for predicting ship resistance reductions possible by this technique. In all cases of pipe flow and submerged body flow, the frictional resistance of flow was substantially reduced by the polymer solutions. The form resistance of the submerged bodies was only affected by the presence of polymer when it changed the flow separation point. There is evidence to indicate that polymer solutions reduce radiated noise from a surface[34,43] and can increase the flow velocity required for the inception of cavitation[35].

The first attempt to measure the reduction in resistance of ship models was by Emerson[36], who towed two different model hull forms, a 7 ft. plank and a pontoon through fresh water and Polyox 301 solutions of up to 50 wppm. He observed decreasing frictional resistance with increasing polymer concentration and Reynolds Number for each towed form. A 50 per cent reduction in frictional resistance as compared with fresh water was observed at a Reynolds Number of 3×10^6 with 50 wppm Polyox concentration. Although the work was aimed at developing a technique to provide an additional scaling factor for model frictional resistance coefficients, Emerson did consider the feasibility of reducing ship resistance by injecting polymer solutions into the ship's boundary layer, concluding however, that 'the quantity of water to be treated is large, and at the moment the idea seems uneconomic'.

Dove[37] measured the reduction in resistance of a frigate model when injecting solutions of Polyox 301 into the boundary layer, obtaining reductions in drag equivalent to up to 30 per cent reduction in frictional resistance. Because this work formed the basis of the full-scale trial, it is considered in more detail later. Hoyt[35] has provided indirect evidence of frictional resistance reduction in model hulls by showing that several marine organisms often present in towing tanks are effective friction reducing agents. A sudden increase in the concentration of these organisms can therefore cause the anomalous changes in resistance observed during towing tank storms[38].

Kowalski[39] calculated that 19,500 lb per hour of polymer would be required to provide a concentration of 20 wppm in the boundary layer for a 300 ft. × 30 ft. submarine at 35 knots. However, based on his measurements of the change in turbulence intensity when injecting polymer solution into water flowing in a small open channel, and assuming that only the viscous sub-layer and not the whole boundary layer needs to be treated, he concluded that a drastic saving in polymer might be possible. This would be accomplished by:

(i) injecting polymer solution tangentially to the surface, thereby reducing the rate of diffusion of polymer away from the surface and encouraging a 'surface effect' which keeps polymer in and near the viscous sublayer;

(ii) injecting solution in pulses, relying on the persistence of the polymer in the boundary layer to maintain a continuous reduction in resistance.

He claimed a hundredfold reduction in polymer consumption could be achieved if both these factors operated simultaneously. This prediction is probably over-optimistic, since the credibility of friction reducing polymers exhibiting a persistence of surface effect has been strongly questioned by Little[40]. Support for

the existence of a surface effect is, however, given by Wu[12].

Lang[41] also considered how the size, power and speed of a submarine could be modified by using polymer injection to obtain reductions in hull resistance. At the other end of the scale, so to speak, are the implications of polymer ejection in competitive rowing and yacht racing, and this is a matter which has received wide publicity[42]. It can be seen therefore that a large amount of documented work exists to indicate that a useful reduction in ship's resistance may be obtained by polymer injection into the boundary layer. However, before the trials reported in this paper were undertaken, only one attempt had been made to verify that the effects observed with pipes, planks and various bodies would apply to a full-scale hull. This was a trial conducted in the U.S.A. in 1963 with a minesweeper, using guar gum as the additive. Due to difficulties in measuring speed the results were not wholly conclusive, but a speed increase of about 5 per cent was indicated with an estimated solution concentration of 40 wppm in the boundary layer.

Mechanism of Skin Friction Reduction

Because concentration solutions of most friction reducing polymers are extremely visco-elastic, several attempts to explain the phenomenon have proposed mechanisms dependent on visco-elasticity[19, 44]. However, very dilute solutions of polymers (less than 100 wppm), whilst exhibiting friction reduction, are Newtonian liquids by conventional viscometry[45], which precludes an explanation based on visco-elasticity for dilute solutions. Several other anomalous properties of these polymer solutions have been studied and rejected as an explanation of friction reduction[46, 47].

The friction reduction obtained for a given polymer under given flow conditions has been found to depend on several parameters, and in general increases with increasing polymer molecular weight, polymer concentration (until the polymer significantly increases the solution viscosity), and Reynolds Number. The age of the polymer solution and the amount of mechanical agitation to which it has been subjected are also of importance, as both appear to degrade the structure of most long chain polymers, reducing their effectiveness as friction reducing agents[12].

Although dilute polymer solutions may affect the nature of free turbulence in the absence of a solid surface, as in a submerged jet[48], they appear to have the greatest effect on flow conditions in the presence of a surface[15,49]. This may be due to polymer absorption on the surface[11], but an increasing weight of experimental evidence both from pipe flow and submerged body-flow studies indicates that the thickness of the laminar sub-layer, and perhaps the transition layer, is increased by the presence of the polymer[16, 17, 29, 50]. Thus at a constant surface shear stress, the velocity of the bulk liquid relative to the surface is increased, or alternatively the frictional resistance is decreased. Lumley[51] has proposed a mechanism in which long-chain polymer molecules resist the formation of streamwise vortices in the sub-layer, leading to greater sub-layer thickness. A similar theory has been suggested by Walsh[52] whereby polymer molecules alter the normal energy balance between the viscous sub-layer and the turbulent boundary layer by destroying or preventing the formation of small eddies. Ultimately this reduces the momentum transfer between the layers, allowing the thickness of the sub-layer to increase.

This continuum mechanism has been questioned by McNally[20] who claims that the frictional resistance of a rough pipe can be reduced by polymers when, because of the surface roughness, a viscous sub-layer could not exist. Such an argument leads inevitably to a particulate or molecular mechanism[10], and it would seem logical that both concepts may ultimately be important in explaining the phenomenon.

Application to Ships

(a) *Model Experiments at AEW*

The work reported by Dove[37] was carried out at the Admiralty Experiment Works in 1965. The resistance of a 16 ft. frigate model was measured in a towing tank while prepared solutions of varying Polyox 301 concentrations were injected into the boundary layer from four supply tanks positioned on the tank carriage. Each tank fed solution to a transverse slot 0·02 in. wide extending from waterline to keel on each side of the model, the four slots being located at distance abaft the FP corresponding to 5, 25 and 50 and 75 per cent of the model length. Polyox concentrations of 100, 250, 500, and 1,000 wppm were used in the tanks, and the model was towed at speeds corresponding to 15 and 30 knots full scale. The model resistance was first measured with no flow from the tanks, and again with tap water in the

tanks at various boundary layer injection rates. Thereafter Polyox solutions were used. At each combination of solution concentration and model speed, the solution was ejected firstly from the five per cent slot (*i.e.* the foremost position), then simultaneously from the five and 25 per cent slots, and so on until all slots were in use.

Dove found the maximum reduction in resistance was obtained with a nominal Polyox concentration of approximately 10 wppm in the boundary layer and that the most effective way of reducing resistance was to use the five and 25 per cent slots simultaneously. With this particular combination of variables, frictional resistance was apparently reduced by 21 per cent at a model speed equivalent to 15 knots. The corresponding apparent reduction at the higher speed was 29 per cent. Dove noted that increasing the nominal Polyox concentration in the boundary layer above 10 wppm produced only a small additional reduction in resistance. Confirmation was therefore obtained from these tests that substantial reductions in skin friction resistance could be obtained with a very dilute polymer solution by continuously injecting the additive into the boundary layer. During the course of further experiments at AEW on the frigate model it was found that hull efficiency was improved by five per cent in the presence of Polyox in the boundary layer. This improvement was mainly due to a change in thrust deduction, wake fraction remaining broadly unaltered. It remained to be seen whether significantly large reductions in resistance could be obtained with solution concentrations as low as 10 wppm on the full scale. Moreover, because of the difficulty associated with scaling up the frictional resistance of rough surfaces, full scale trials would provide the only means of establishing whether substantial reductions in resistance could be obtained with a ship's hull in a state more representative of normal operating conditions than the smooth and rough surfaces used in various tank and laboratory tests. It was therefore decided to undertake ship trials for the purpose of evaluating these scale effects.

(b) *Problems of Scaling Up*

Polyox 301 was selected as the friction reducing polymer to be used during the ship trials because it had been used in many previous investigations, including the model frigate tests, and it was commercially available in tonnage quantities. In the towing tank tests, the Polyox 301 solution had been prepared in advance and stored in tanks on the towing gantry. However, preliminary calculations showed that it would be impossible to store sufficient pre-mixed solution on board for a full scale trial. The practical alternatives to the storage of Polyox 301 in solution were as a suspension in a suspending liquid (*e.g.* ethylene glycol) or as a powder. The relative merits of the three methods of storage are compared in Table 1.

TABLE 1.

Method of Storage	*Concentration of Stored Polyox 301 (per cent)*	*Density*	*Packing Density (g. Polyox 301/cm^3)*
Solution	0·5	1·00	0·005
Suspension in ethylene glycol	20	1·12	0·22
Powder	100	0·46	0·46

Clearly storage as a powder is the most efficient in terms of weight and volume and has the added advantage that:—

(i) Problems associated with suspensions are eliminated. Suspensions of Polyox 301 are difficult to stabilise, since the Polyox gradually settles to the bottom of a storage vessel, making agitation necessary to redisperse it before use. Large quantities of the suspending liquid have to be stored and handled as well as Polyox 301.

(ii) Polyox 301 is supplied as a free-flowing powder by the manufacturer.

Storage of Polyox as a powder was therefore adopted for the ship trials. The design of the powder/water mixer was obviously a key item in the success of the system as a whole. Small scale tests with a commercial powder/water mixer indicated that the concept of continuously mixing Polyox 301 powder and water to form solutions was feasible, although several limitations in the design became apparent. Nevertheless, the principle of the mixer was used to design the much larger unit needed for the trial.

Preparations for Full Scale Trials

(a) *Ship*

A coastal minesweeper was selected for the trials in preference to a frigate, as the former represented an acceptable compromise between the opposing requirements of minimising the cost of experimenting on the full scale and of maximising the scale ratio between model tests and ship trials. Approval was given to utilise

H.M.S. *Highburton* for a three week trials period immediately following a dockyard refit, during which the opportunity was taken to prepare the ship for trials. Particulars of H.M.S. *Highburton* are given in Table 2.

TABLE 2.

General Ship Particulars

Dimensions	
Length Overall	152 ft. 0 in.
Length Between Perpendiculars	140 ft. 0 in.
Breadth Extreme	28 ft. 0 in.
Propeller Particulars	
Number of Propellers	2
Number of Blades	3
Diameter	6 ft. 0 in.

The preparatory work undertaken during the refit consisted of securing a housing on the fore-deck containing the Polyox solution generating equipment and associated pumps and valves, and the attachment to the hull of four external ducts containing ejection slots. Piping was run between the housing and the three separate inlets to each duct. The ejection slots, which were 0·07 in. wide, were designed to inject Polyox solution into the boundary layer at an angle of five degrees to the hull surface at a maximum velocity of 8 ft. per sec. The forward ducts were located Port and Starboard with the slots 5 ft. 3 in. (four per cent LBP) from the FP. The after ducts were located 35 ft. 3 in. (25 per cent LBP) from the FP. Further details of the ducts and slots are shown in Figs. 1 and 2.

H.M.S. *Highburton* has a double skin wood hull which is protected by standard Pocoptic anti-fouling compositions and boot-topping. The accumulation of numerous coats of these compositions had made the surface of the hull extremely rough. The underwater portion of the hull was lightly scraped and one coat of protective and one coat of anti-fouling paint was applied immediately prior to undocking. The hull was considered rough by usual standards. Some of the planks were standing proud of adjacent planks and splintering of the plank edges was general.

(b) *Solution Generating System*

The model frigate tests by AEW had indicated the general range of conditions that should be explored in a ship trial. However, these had

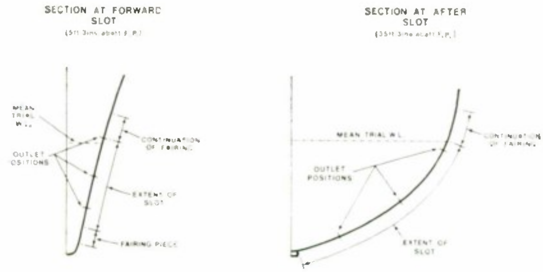


FIG. 1. Sections showing extent of ejection slots.

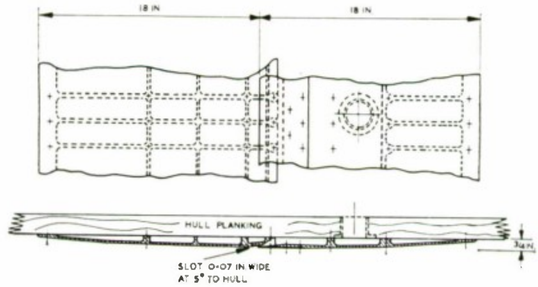


FIG. 2. Details of fairing, duct and ejection slot.

to be tempered by the practical considerations of available power, storage volume and extra weight that could be accommodated by the ship. The requirements for the system therefore became:—

(i) to be capable of providing sufficient Polyox solution to fill the ship's boundary layer to a concentration of five wppm Polyox at the ship's maximum speed of 16 knots.

(ii) to utilise 70 ton/hr. portable fire pumps to pump seawater into and solution out of the system.

(iii) to store up to ½ ton of Polyox for use when it was being consumed at the maximum rate.

(iv) to be capable of "pulsing" the Polyox solution to different inlets of the ejection slots in sequence. This requirement was to test the hypothesis of Kowalski[39] that Polyox solutions are persistent in reducing drag for several seconds after the supply has been cut off.

The design of the unit built for the ship's trials incorporated the following features:

(i) The unit was self-contained, for easy installation on the forecastle deck of the minesweeper in place of a Bofors gun.

(ii) The unit had to be divided into two distinct compartments; one was the upper "dry" section used to store dry powder in bags, and dispense the powder through a hopper and feeder to the powder/water mixer, and the other was the lower "wet" section containing the solution mixing tank, pipework, valves and instruments. Because Polyox dust in a confined space forms a potential explosion hazard, all electrical wiring in the upper section of the hut conformed to explosion proof regulations.

(iii) A mixing tank following the powder/water mixer allowed a delay of at least one minute before the solution was pumped down to the ejection slots. This delay was necessary to allow the powder particles dispersed in the water by the mixer to go into solution. Chemical analysis showed that up to 80 per cent of the added powder was in solution after hold-up in the tank.

(iv) The flow rate of solution pumped out of the system to the ejection slots on the hull was measured by a magnetic flow meter. This meter measures the mass flow rate of material flowing through an essentially plain tube and is independent of flow profile, viscosity, visco-elasticity, or pressure drop; it is thus ideal for measuring the flow rates of these non-Newtonian visco-elastic solutions.

Fig. 3 is a flow diagram of the system showing the pipe sizes.

It was decided to use the Polyox powder exactly as bought. Grinding or sieving would have decreased the average particle size and thereby reduced the time required for dissolving the powder, but this was not attempted because of the large amount of powder required for the trial (two tons). It was, however, found necessary to blend the different batches of powder supplied in order to eliminate batch to batch variations in powder feed rate into the mixer.

Full details of the solution generating system are given in the AEW/AML report on the trial[53].

The Trials

(a) *Trials Procedure*

Before the start of the trial the Polyox generation and ejection system was tested in dry dock. The trial was conducted in Stokes Bay during the period 4th - 24th September, 1968. The ship was six days out of dock at the beginning of the period.

The ship's speed log was not accurate enough for recording propulsion data, so all performance runs were made over the measured mile course. On 17th, 18th and 19th September, 1968, runs were made elsewhere while experiments were carried out on the Polyox distribution system.

The procedure adopted was first to establish the basic propulsive performance of the ship without any form of boundary layer injection. Runs were then made with sea water injected at various rates into the boundary layer. The results showed that sea water injection did not affect the basic performance of the ship. Thereafter the procedure followed each day was to carry out a limited number of datum runs before starting to inject Polyox solution.

Torsionmeter zero readings were obtained before and after trials each day. During each run on the measured mile wind speed and direction were recorded autographically. Rudder angle and sea state were kept under observation.

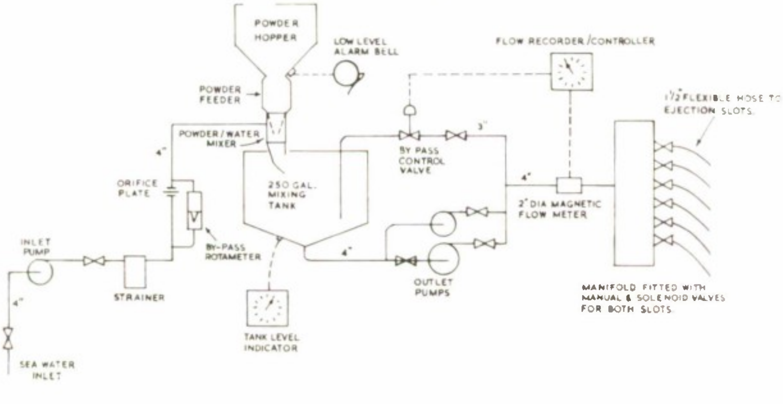


FIG. 3. Flow diagram of solution mixing system.

At first the trial was conducted only when weather conditions were favourable, but owing to shortage of time some of the later runs had to take place under rather unfavourable conditions. Up to 16th September winds had been light and there was no swell in the area, but a gale developed on 20th September which delayed further work. When the trial was resumed on 23rd September there was a strong wind, waves 2 ft. high and a slight swell. These wave conditions persisted on 24th September after the wind had moderated considerably.

(b) *Operation of the Polyox System*

In general the system for continuously preparing solution from dry powder and seawater performed satisfactorily and confirmed that this concept for preparing solutions was viable; 135 gall./min. of 2,500 wppm Polyox solutions were prepared continuously for several hours, and 250 gall./min. were prepared for short periods without serious problems. The mixer operated efficiently for several hours over the following ranges of conditions:—

Sea water throughput	50 - 250 gall./min.
Polyox throughput	0 - 6 lb/min.
Solution concentration	0 - 3,750 wppm Polyox

The maximum solution concentration prepared was 6,000 wppm but due to the high viscosity of this solution (above 100 cP) it was difficult to pump it in sufficient quantity to the ejection slots.

The position of the seawater intake proved unsuitable under certain circumstances. When ejecting solutions at ship's speeds above 9 knots, it was not possible to maintain reliably an inlet water flow rate above 135 gall./min., and the flow rate fluctuated considerably when the ship manoeuvred. In consequence this flow rate was used for most conditions towards the end of the trial, although it was less than desired.

Solution was prepared and ejected continuously during a series of speed runs, both when the ship was actually on the measured mile, as well as when manoeuvring at the ends of the mile course. Changes in the solution concentration or flowrate between runs usually required 10 - 15 min. to establish the new conditions. Changes in ejection slot geometry only involved opening or closing appropriate valves, and could be achieved within 1 - 2 min. The Polyox solutions always contained entrained air resulting from the high degree of liquid turbulence necessary to ensure rapid wetting out and solution of the powder.

(c) *Boundary Layer Sampling*

To obtain a picture of the Polyox distribution around the hull and how the distribution varied with ejection conditions and geometry, 13 sample points were fitted at different positions along the ship's length and girth on the starboard side. Their positions, together with those of the ejection slots and water intake, are shown in Fig. 4. At each sample point a tube, $\frac{1}{8}$ in. inside diameter, penetrated the ship's hull, the outer end terminating flush with the planking. Inside the ship, the pipes were fitted with stopcocks and connected to 600 ml. sample bottles.

A portable drag-reduction test meter, based on a hypodermic syringe, was developed to analyse rapidly the samples during the trials. A 2 ml. sample was drawn into the syringe through a 45 cm. length of 1 mm. bore capillary tubing. This liquid was then ejected by a spring pushing the syringe plunger down. Two microswitches were set to operate as the plunger passed into and out of the mid-section of its travel and the time between their operation was indicated on a digital clock. The spring was selected to give turbulent flow inside the capillary tube during the sample ejection, the average Reynolds Number being 2×10^4. Consequently, the presence of drag-reducing agents in the sample reduced the effective flow resistance of the capillary tube, increasing the ejection flow rate and reducing the indicated time. The instrument was calibrated with solutions of known Polyox content before the trial. The slope of the curve relating ejection time to concentration, shown in Fig. 5 is such that concentrations in the 0 to 10 wppm range may be readily determined to the nearest 1 wppm range and estimated to $\frac{1}{2}$ wppm. Above 19 wppm the slope decreases rapidly, passes through zero and increases with reversed sign. Analysis of samples in this concentration range were effected by diluting to bring the concentration below 10 wppm.

During the trial a set of samples was collected during a run over the measured mile and analysed on board during the return run.

Results of Ship Trial

Corresponding pairs of datum and Polyox mean results have been adjusted to speeds of 9, 12 and 15 knots as appropriate in order to provide a common basis for comparison. The adjusted results are given in Table 3 together with the Polyox solution ejection conditions

TABLE 3.

Comparison of Speed Trial Data with and without Polyox Ejection, corrected for Wind.

Nominal Speed	*Datum*		*Polyox*							*Percentage Difference from Datum*	
Knots	*Shp*	*Thrust Tons*	*wppm at Outlet*	*Flow Rate gal/min*	*Equivalent wppm in BL*	*Average wppm positions 3, 4 & 5*	*Ducts* operating*	*Shp*	*Thrust Tons*	*Shp*	*Thrust*
	189	1·49	4,800	220	13·1	2·3	C	160	1·35	−15·3	−9·4
	198	1·64	5,900	133	9·8	3·0	C & D	166	1·47	−16·2	−10·4
	198	1·64	3,750	133	6·3	3·7	C & D	159	1·34	−19·7	−18·3
	198	1·64	2,925	133	5·0	2·0	C & D	176	1·47	−11·1	−10·4
	189	1·49	1,925	210	5·0	1·2	C	157	1·29	−17·0	−13·4
9	189	1·49	3,000	133	4·9	1·2	C & D	172	1·40	−9·0	−6·0
	179	1·54	2,800	133	4·7	1·8	C & E	163	1·33	−8·9	−13·5
	179	1·54	2,800	133	4·6	2·6	C & E	163	1·37	−8·9	−11·0
	189	1·49	900	220	2·5	0	C	176	1·46	−6·9	−2·0
	–	1·60	1,800	80	1·8	2·2	C	–	1·40	–	−12·5
	–	1·55	2,900	26·4	0·7	0	A	–	1·50	–	−3·2
	–	1·55	1,600	26·4	0·5	–	C	–	1·50	–	−3·2
	–	1·55	1,520	26·5	0·5	0	B	–	1·55	–	0
	519	3·68	2,520	133	3·4	1·5	C	468	3·37	−9·4	−8·4
	528	3·80	2,400	133	3·2	1·7	C & D	490	3·57	−7·2	−6·1
	504	3·72	2,400	133	3·2	1·6	C & E	482	3·50	−4·4	−5·9
12	–	3·57	2,300	114	2·6	1·1	C	–	3·50	–	−2·0
	–	3·64	2,320	38	0·9	0·3	C	–	3·32	–	−8·8
	–	3·64	1,600	38	0·6	0	B	–	3·48	–	−4·4
	–	3·64	1,280	38	0·4	0	A	–	3·55	–	−2·5
	–	8·63	2,520	146	3·0	0·8	C	–	8·65	–	+0·2
	–	8·97	2,440	49	1·0	0	B	–	8·40	–	−6·4
15	–	8·97	2,320	49	0·8	–	C	–	8·59	–	−4·2
	–	8·97	2,320	49	0·7	0	A	–	8·66	–	−3·5

* A—Using forward duct only. B—Using aft duct only. C—Using both ducts. D—Bottom valves shut. E—Lower portion of ducts blanked off.

and average boundary layer concentrations during each double run on the measured mile. The equivalent boundary layer concentration given in the table is defined as the product of the ejected solution concentration and flow rate divided by the boundary layer flow rate, and the average boundary layer concentration is the average observed at sample positions 3, 4 and 5. The results have been arranged in decreasing order of equivalent boundary layer concentration.

Fig. 6 shows the results of the datum and Polyox speed runs as group mean total shp and thrust, both corrected for wind, plotted against ship's speed. Separate plots are given for nominal speeds of 9, 12 and 15 knots. In each case the appropriate parts of the datum curves of shp and thrust have been included.

The detailed trial results and their interpretation are covered more fully in AEW/AML trials report[53].

Discussion

Effect of Polyox on Propulsive Performance

The results in Table 3 show that reductions in thrust were obtained in every case but one when Polyox was ejected into the boundary layer. In all cases where shp was measured, a reduction in shp was obtained which was generally greater than the corresponding reduction in thrust.

The results obviously contain a certain amount of scatter due to random errors in the measurements, which are magnified in the process of taking differences. This is likely to be the case particularly at 9 knots, where the absolute values of measured shp and thrust are relatively small.

A clear trend in these results is for larger percentage reductions in shp to be associated with higher expected concentrations of Polyox in the boundary layer. There is a similar trend in the thrust results, although not so well

defined until results are grouped together and averaged in order to reduce the effect of random errors. This has been done to obtain the results in Table 4. Differences in shp and thrust have been averaged over limited ranges of expected Polyox concentration. The average for each range is also given in this table.

None of the datum thrust readings exceeded the calm water datum by more than $5\frac{1}{2}$ per cent at 9 knots. The corresponding values of 12 and 15 knots were $3\frac{1}{2}$ and $2\frac{1}{2}$ per cent respectively. Since allowance has been made for the effect of wind in the results, the above percentages are a measure of the worst effects of

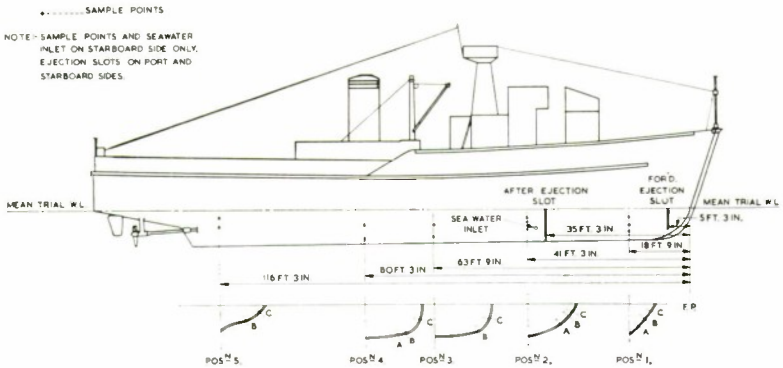


FIG. 4. Position of ejection slots and sample points.

Average shp reductions shown in Table 4 are somewhat larger than corresponding thrust reductions. This would be expected if the presence of Polyox in the boundary layer affected thrust deduction more than wake fraction, and the trial results therefore show the same trend as the frigate model tests at AEW.

The results in Table 4 based on the measured thrust changes at 9 knots have been plotted against the estimated Polyox concentration in Fig. 7. Also included in this figure is a curve derived from the frigate model tests when ejection slots at 5 and 25 per cent of the length from the bow were used in combination. The frigate results were obtained at a speed corresponding to Fn=0·234, approximating to H.M.S. *Highburton* at 9 knots. Because of the differences in hull form and scale, and the existence of a substantial degree of roughness on the ship's hull, close agreement between the curves would not be expected. However, there is an obvious similarity in the results which is encouraging, particularly as some of the runs took place in weather conditions which were not too favourable for full scale experiments of this nature.

The values of expected Polyox concentration used in Tables 3 and 4 and Fig. 7 do not necessarily represent the true state of affairs in the boundary layer. However, the same consideration applies to the frigate model test results shown in Fig. 7 and therefore the comparison is a valid one.

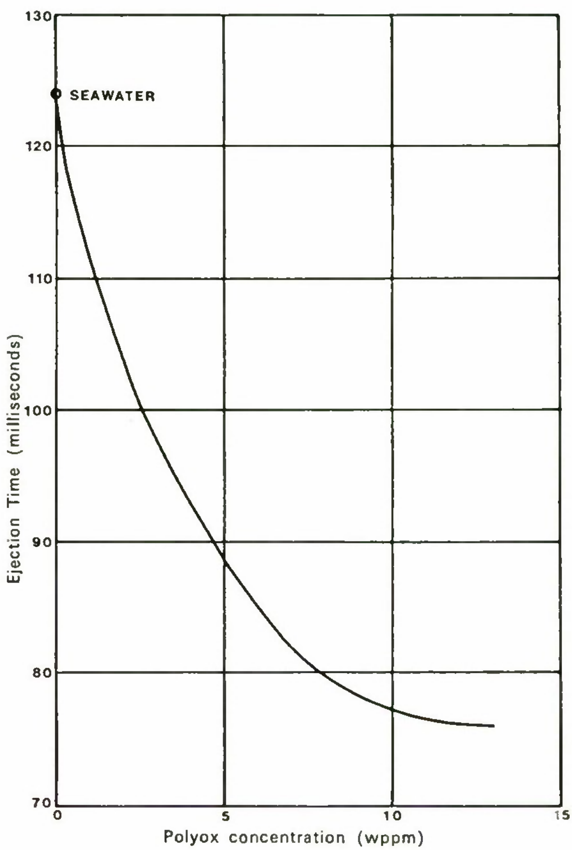


FIG. 5. Calibration curve for drag reduction meter.

sea state during the trials. It is noteworthy that some of the largest reductions in shp and thrust were obtained with the maximum output of Polyox and this occurred when weather conditions were least favourable.

A great deal of time was spent during the trial attempting to improve the distribution of Polyox and it was principally for this reason that the facility of pulsing the flow to the ejections slots was not used during runs on the measured mile.

Boundary Layer Samples

The boundary layer samples revealed that the Polyox distribution around the hull was not at all uniform, the higher concentrations usually appearing at the sample points closest to the keel. In an attempt to obtain a more uniform distribution, solution was pumped to the forward and aft slots separately as well as to different inlets to the slots. These runs revealed that feeding the top inlet only to each slot produced the best distribution around the hull.

TABLE 4.

Average Estimated Polyox Concentrations in Boundary Layer and Corresponding Average Power and Thrust Differences.

Speed Knots	*Number of Results Averaged*	*Estimated Polyox Concentration in Boundary Layer. Wppm* — *Range*	*Average*	*Average Percentage Difference* — *Shp*	*Thrust*
9	3	6·3 - 13·1	9·7	−17·1	−12·7
	5	4·6 - 5·0	4·8	−11·0	−10·9
	5	0·5 - 2·5	1·2	—	− 4·2
12	3	3·2 - 3·4	3·3	− 7·0	− 6·8
	4	0·4 - 2·6	1·1	—	− 4·4
15	4	0·7 - 3·0	1·4	—	− 3·5

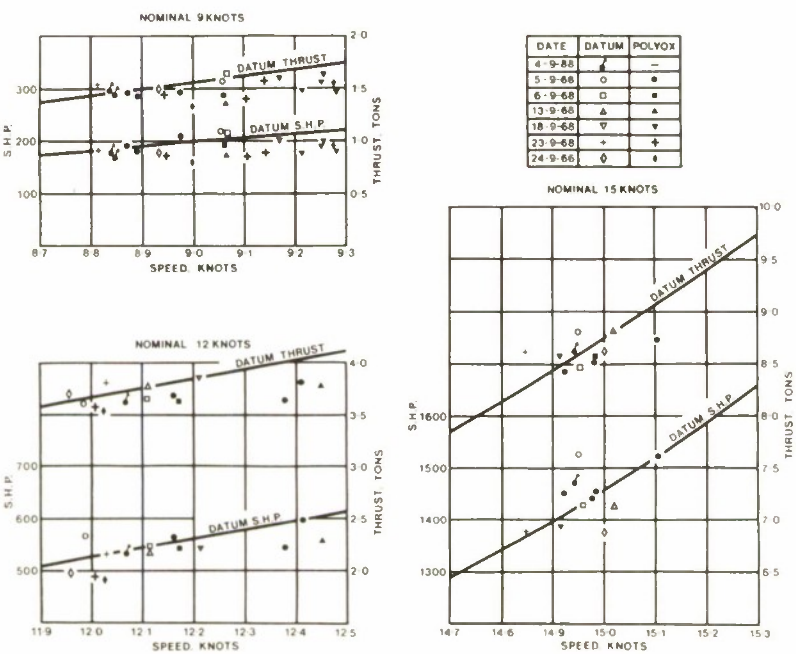


FIG. 6. Speed trial results with and without Polyox ejection.

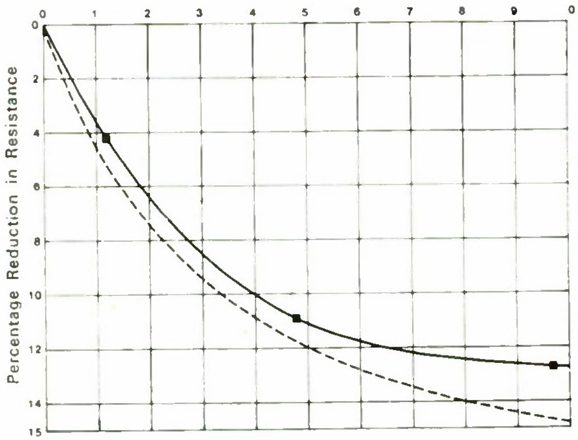


FIG. 7. Variation of total resistance with Polyox concentration in boundary layer.
——— Frigate model (F_N= 0·234)
- - - - - Highburton at 9 Knots (F_N=0·226)

This arrangement was used for the remainder of the trial, with the lower 50 per cent of both slots physically blocked with strips of balsa wood.

Because of this uneven distribution of Polyox in the inner boundary layer, model tests were undertaken after the trials to investigate the flow conditions over the fore end of the ship.

It was clearly established by these tests that a considerable degree of sweepdown must have occurred at the forward ejection slot in *Highburton* at all speeds. Thus a large proportion of the Polyox ejected at this position must have been swept down towards the keel. This is consistent with the distribution of Polyox observed in the boundary layer samples taken at the foremost position. There is similar corroboration between the indicated flow directions and boundary layer concentrations behind the after ejection slot.

The curves in Fig. 7 show that concentrations greater than 10 wppm have little more effect than 10 wppm and hence the distribution in the keel area appears to have been wastful. Further, the measured concentration along the sides above the turn of bilge was generally very low and hence frictional resistance reduction may have been correspondingly low in these areas. Further research on these aspects is obviously necessary.

Assessment

Commercial Considerations

The principal achievement of the trial was to demonstrate that significant reduction in resistance can be obtained by injecting Polyox solution into the boundary layer of a ship's hull. On the basis of a straight comparison between the cost of Polyox ejected and the saving in fuel to achieve the same speed, it can be readily shown that the scheme, as tested, was far from economically viable. In order to obtain an average reduction in shaft horsepower of 17 per cent at nine knots, an average Polyox powder feed rate equivalent to 3·7 tons/day was required. The resultant saving in diesel fuel amounted to about 0·18 tons/day, a weight ratio of about 21 against the use of Polyox. Current prices of Polyox powder and diesel fuel are £840 per ton and about £11½ per ton respectively, a cost ratio of 73 in favour of diesel fuel. So the cost of Polyox consumed was some 1,500 times the cost of fuel saved. On the face of it, therefore, there does not appear to be any prospect at all of using boundary layer additives for commercial reasons. However, it is important to consider what might be achieved in future having regard to the lessons learnt from the trial, and from the considerable volume of research work currently being conducted in laboratories throughout the world.

It is also important to remember that the benefits of using boundary layer additives are not necessarily confined to the possible commercial advantages of reducing frictional resistance. If the latter effect is due to a reduction in turbulence intensity within the boundary layer, it is likely to be accompanied by a reduction in flow noise, which could be an important advantage in naval operations. The same consideration applies to the possible effect of boundary layer additives on cavitation inception.

Advantage can be taken of a reduction in resistance by utilising available machinery power to achieve a higher speed in service. This advantage can only be obtained at a price. In the case of any boundary layer additive, the price to be paid is compounded of the following factors:

(i) Increased capital costs, covering storage facilities; mixing delivery and control system; ejection slots.
(ii) Increased maintenance costs, because none of the additive equipment will replace existing propulsion machinery.
(iii) Increased voyage disbursements. These will be principally composed of expenditure on boundary layer additive.
(iv) Loss of cargo deadweight because additive must be carried in order to sustain the reduction in resistance.

It is difficult to evaluate items (i) and (ii) at the present time, since the precise form of equipment to be used will obviously depend upon the nature of the additive to be employed. It is likely, however, that these additional costs will be very small in relation to normal capital costs and hence they are likely to be major factors in any economic assessment. They are in any case unlikely to represent a proportion of capital cost which diminishes as ship size is increased.

Item (iii) is clearly a major factor. It should include the cost of providing power for mixing and distributing additive solution to ejection slots and any increase in crew costs necessary to ensure the reliable operation of the system, but these are likely to be relatively minor considerations compared with the cost and weight requirement of the additive itself. The latter is governed by the volume of flow in the boundary layer, which is primarily a function of ship size and speed. For geometrically similar ships operating at constant Froude Number, the additive weight requirement, expressed as a ratio of loaded displacement, is reduced to approximately one-third as the length of the ship is doubled; the corresponding figure at constant speed is between one quarter and one third. Hence there appears to be a greater prospect of utilising a boundary layer additive to advantage in a large ship than a small one. A similar consideration applies to item (iv).

For this reason preliminary studies have been made of the boundary layer additive requirements in a large containership and a supertanker. Particulars of the ships are given in Table 5. These types of ships were chosen because they represent different ends of the scale, in the sense that the tanker carries a large weight of relatively low-valued cargo at moderate speed against what is predominantly frictional resistance, whilst the containership carries a smaller weight of relatively high-valued cargo at high speed and hence incurs a total resistance which includes a substantial proportion due to wave-making effects. In making these studies it was assumed that advantage could be taken of future research work to obtain a reduction of 30 per cent in frictional resistance with an average boundary layer concentration of 0·1 wppm polymer. This might be achieved by using an advanced ejection technique to maintain a sufficiently high concentration of polymer close to the hull surface.

The figure chosen for resistance reduction is the best achieved during model tests at AEW.

TABLE 5.

Boundary Layer Additive Requirements for a Containership and Supertanker.

		Containership	*Supertanker*
Length between perpendiculars	ft.	700	1,000
Breadth moulded	ft.	100	175
Draught	ft.	35	72
Number of screws		2	1
Propulsion machinery		steam turbines	steam turbines
Service power	shp	45,000	35,000
Service speed (without Polyox)	knots	23	16
(with Polyox)	knots	24	17½
Fuel consumption	tons/day	225	175
Polyox consumption	tons/day	1·85	3·94
Fuel cost	£/day	1,350	1,050
Polyox cost	£/day	1,550	3,310
Polyox consumed to save one day at sea by increasing speed	tons	42·6	42·1

On the other hand, obtaining this result whilst at the same time reducing the additive requirement to one per cent of that having greatest effect in *Highburton* is obviously an immensely difficult target.

The estimated increased service speeds expected to be attainable with Polyox ejection while maintaining normal service power are shown in Table 5 together with the estimated weight and cost of fuel and Polyox. For costing purposes, the price of Polyox was taken at £840 per ton and of fuel oil as £6 per ton.

Table 5 shows the effect of using Polyox would be to increase the service speed of the containership from 23 knots to 24 knots at the expense of doubling the overall 'fuel' cost; in the case of the tanker, the service speed would be increased from 16 to 17½ knots for a threefold increase in overall 'fuel' cost. The Polyox weight requirement is only about one per cent of the fuel weight requirement of the containership and about two per cent in the case of the tanker. Loss of cargo deadweight due to carrying sufficient Polyox would not therefore appear to be a significant factor, particularly in the containership. If Polyox was used to maintain normal service speed of 16 knots in the tanker, the resulting saving in fuel

would be 60 tons a day as compared with a Polyox weight requirement of 3·64 tons per day and so cargo deadweight could actually be increased. Thus, even if the amount of Polyox required to reduce frictional resistance by 30 per cent was increased ten-fold the weight consumption of Polyox would still be less than that of the fuel saved. In the containership the Polyox consumption rate could be increased 20 times since 45 tons per day of fuel would be saved while maintaining 23 knots and consuming Polyox at 1·78 tons per day.

The containership would save about one day in 23 by increasing speed from 23 to 24 knots; the tanker would save one day in 12. Assuming that the interest rate on the cargo value is 10 per cent, the resulting 'value' of ship's time becomes £274 per day per £1 million of cargo value. It would obviously be uneconomical if the extra cost of using boundary layer additives to increase speed exceeded this value. The price of additive would therefore have to be not more than £65 per ton for the containership carrying £10 million worth of cargo, and £6·5 per ton for the tanker carrying £1 million worth of cargo. These prices would have to be lower still if other increased costs were taken into consideration. This is a rough measure of the target price which would have to be achieved.

What emerges clearly from these figures is the need drastically to reduce the cost of using boundary layer additives before any commercial advantage can be gained by their use.

However, having regard to the fact that estimates are based on the attainment of an additive distribution system one hundred times more effective than that achieved during the trials in *Highburton*, the prospect of utilising a boundary layer additive economically in a ship seems a long way off at the present time, unless more effective means are developed of utilising the additive, and far cheaper additive materials become available. It is therefore interesting to speculate on the future prices of various types of boundary layer additives.

Polymer Developments

Polyox WSR 301 is an efficient resistance reducing agent by current standards. At present one company is the sole manufacturer. A recently constructed plant has raised output capacity from approximately 1,000 tons per year to 10,000 tons per year, but the price has remained unchanged in the region of 40p per lb. However, this new output is still small compared, for example, with the output of low density polyethylene in the USA, which amounts to approximately one million tons per year. At this level and in a strongly competitive market, the price of polyethylene has fallen to about 7p per lb. It seems unlikely that polyethylene oxide will drop to this level, although 15p per lb. might well be possible if sufficient demand could be found. The most that can be expected therefore seems to be a reduction to about one-third of the present price to £260 per ton, considerably greater than a target price of under £65 per ton.

Larger molecules give greater drag reductions for unit weight of material. Thus Polyox FRA (molecular weight approximately 10×10^6), which is now commercially available, is more effective than WSR 301, although this improvement is partly offset by the increased cost of the higher molecular weight polymer. This trend in price will unfortunately be true in general for all polymers.

Present knowledge suggests that the ideal drag reducing molecule is water soluble, linear, flexible, and of high molecular weight. Polyethylene oxides possess these attributes to a degree which appears difficult to improve upon. Of the alternative water soluble polymers, only the polyacrylamides compare favourably with Polyox. The best grades give reductions equal to those of WSR 301 at lower concentrations. However, they are currently slightly more expensive than Polyox.

Other materials, such as asbestos and nylon filaments, have been used as drag reducing agents. The concentrations required (up to 10,000 wppm) are considerably higher than required by good polymers, and prices of these materials are not correspondingly lower. In addition their increased bulk could present storage problems for shipboard use.

Thus there is little likelihood at present of obtaining an additive which will be cheap enough to be used on a commercial scale for reducing ship resistance.

Conclusions

1. It has been demonstrated by conducting sea trials in the coastal minesweeper *Highburton* that a substantial reduction in frictional resistance is achievable by the use of Polyox WSR 301 as a boundary layer additive on the full scale.

2. Judging by the results of Polyox ejection tests carried out at AEW on a frigate model there are no unexpected scale effects and model tests can therefore be used as a means of developing more efficient boundary layer ejection systems.
3. A shipborne system has been developed to prepare friction reducing solution from stored Polyox powder and sea water under continuous operating conditions. This performed satisfactorily over a wide range of conditions.
4. Boundary layer samples analysed for Polyox content revealed:
   (i) A substantial discrepancy between the amount of Polyox ejected from the ship's hull and that detected in the boundary layer, suggesting a considerable loss of Polyox from the boundary layer.
   (ii) Non-uniform distribution of Polyox around the ship's girth.
   (iii) Lower concentrations in the boundary layer at high ship's speeds.

   These phenomena are consistent with the flow conditions aroung the *Highburton's* hull as determined subsequently by model tests.
5. It is considered technically feasible to reduce full scale resistance by the use of boundary layer additives and that adequate additive storage arrangements can be made in large ships.
6. Commercial advantage cannot be gained by the use of boundary layer additives unless drastic reductions are achieved in additive requirements and cost.

References

[1] Toms, B. A. "Some Observations on the Flow of Linear Polymer Solutions through Straight Tubes at Large Reynolds Numbers". *Proc. Int. Cong. Rheology, Amsterdam,* **2**, 135, (1949).

[2] Fabula, A. G. "The Toms Phenomenon in the Turbulent Flow of Very Dilute Polymer Solutions". *Proc. Int. Cong. Rheology*, **3**, 455 (1963).

[3] White, A. "Turbulent Drag Reduction by using Dilute Polymer Solution instead of Water". *Hendon College of Technology Research Bulletin, No. 3*, 58 (1966).

[4] Meyer, W. A. "A Correlation of the Frictional Characteristics of Turbulent Flow of Dilute Viscoelastic Non-Newtonian Fluids in Pipes". *A. I. Ch. E. J.*, **12**, 522 (1966).

[5] Hoyt, J. W. "Turbulent Flow Properties of Deoxyribonucleic Acid Solution". *Nature,* **211**, 170 (1966).

[6] Hoyt, J. W., and Soli, G. "Algal Cultures: Ability to Reduce Turbulent Friction in Flow". *Science*, **149**, 1509 (1965).

[7] ——, "The Influence of Polymer-Secreting Organisms on Fluid Friction and Cavitation". *Naval Ordnance Test Station Report No. TP/4364*, June 1967.

[8] Kenis, P. R. "Drag Reduction by Bacterial Metabolites". *Nature,* **217**, 940 (1968).

[9] Bobkowicz, A. J. and Gauvin, W. H. "Effects of Turbulence on the Flow Characteristics of Model Fibre Suspensions". *Chem. Eng. Sci.*, **22**, 229, (1967).

[10] Hershey, H. C. and Zakin, J. L. "A Molecular approach to Predicting the Onset of Drag Reduction in the Turbulent Flow of Dilute Polymer Solutions". *Chem. Eng. Sci.*, **22**, 1847 (1967).

[11] Little, R. C. "Drag Reduction by Dilute Polymer Solutions in Turbulent Flow". Naval Research Lab Report 6542 May 1967.

[12] Wu, J. "Drag Reduction in External Flows of Additive Solutions". Viscous Drag Reduction. Plenum Press, p.331 (1969).

[13] Ram, A., Finkelstein, E., and Elata, C. "Reduction of Friction in Oil Pipelines by Polymer Additives". I. and E.C. Fundamentals, **6**, 309 (1967).

[14] Elata, C. and Tirosh, J. "Frictional Drag Reduction". *Israel J. Tech.*, **3**, 1 (1965).

[15] Goren, Y. and Norbury, J. F. "Turbulent Flow of Dilute Aqueous Polymer Solutions". A.S.M.E. **89**, Series D, No. 4, 814 (December 1967).

[16] Squire, W., Castro, W. and Costrell, J. "Mechanism of Turbulent Friction Reduction in Pipes by Dissolved Additives". *Nature,* **213**, 1008 (1967).

[17] Ritter, H. and Messum, L. T. "Skin Friction and Velocity Distribution in a 76 mm Pipe with Polymer Injection". Admiralty Research Lab. Report, April 1967.

[18] White, A. "Flow Characteristics of Complex Soap Systems". *Nature,* **214**, 585 (1967).

[19] Metzner, A. B. and Park, M. G. "Turbulent Flow Characteristics of Viscoelastic Fluids". *J. Fluid Mech.*, **20**, 291 (1964).

[20] McNally, W. A. "Heat and Momentum Transport in Dilute Polyethylene Oxide Solutions". Naval Underwater Weapons Research and Eng. Station Tech. Report No. 44, December 1968.

[21] Lindgren, E. R. "Friction Reduction Effects on Turbulent Flows of Water in Rough Pipes by Dilute Additive of High Molecular Weight Polymer". Oklahoma State University, Technical Report No. 1, 1965.

[22] Barnes, H. A. and Walters, K. "Dynamic Similarity and Drag Reduction in Flow of Elastic Liquids through curved Pipes". *Nature,* **219**, 57 (1968).

[23] Barnes, H. A. and Walters, K. "Flow of Elastic Liquids through Curved Pipes". *Nature,* **216**, 366 (1967).

[24] White, D. A. "Drag Coefficients for Spheres in High Reynolds Number Flow of Dilute Solutions of High Polymers". *Nature,* **214**, 277 (1966).

[25] Sanders, J. V. "Drag Coefficients of Spheres in Polyox Solutions". Intern. Shipbuilding Progress, **14**, 140 (1967).

[26] White, A. "Drag of Spheres in Dilute High Polymer Solutions". *Nature,* **216**, 994 (1966).

[27] Levy, J. and Davis, S. "Drag Measurements on a Thin Plate in Dilute Polymer Solutions". Intern. Shipbuilding Progress, **14,** 166 (1967).

[28] Love, R. H. "The Effect of Ejected Polymer Solutions on the Resistance and Wake of a Flat Plate in a Water Flow". Hydronautics Inc. Report TR-353-2, June 1965.

[29] White, F. M. "Analysis of the Effect of a Polymer Additive on Turbulent Wall Friction and Pressure Fluctuations". Naval Underwater Sound Lab. Report No. 881, 1967.

[30] Barenblatt, G. I., Bulina, I. G. and Myasnikov, V. P. "Effect of Solutions of Certain High Molecular Weight Compounds on the Reduction of Drag in the Flow of a Turbulent Stream Around a Body". *Prikl. Mekh i Tekhn Fiz.*, **3,** 95 (1965). (In Russian).

[31] Baronet, C. N. and Hoppmann, W. H. "Drag Reduction Caused by High Polymer Solution Injected into Water Flowing Around Cylindrical Bodies". Rensselaer Polytechnic Institute 1966.

[32] Vogel, W. M. and Patterson, A. M. "Experimental Investigation of the Effect of Additives Injected into the Boundary Layer of an Underwater Body". Proc. 5th ONR Symposium on Naval Hydrodynamics, Bergen 1964.

[33] Lang, T. G. and Patrick, H. V. L. "Drag of Blunt Bodies in Polymer Solution". A.S.M.E. Publication 66-WA/FE-33, 1966.

[34] Hoyt, J. W. "Radiated Noise of Experimental Torpedoes with Several Noise-Reduction Techniques". 22nd Navy Symposium on Underwater Acoustics, Paper J4, 1964.

[35] Hoyt, J. W. "Micro-Organisms—Their Influence on Hydrodynamic Testing". Naval Reviews, **21,** 18 (1968).

[36] Emerson, A. "Model Experiments Using Dilute Polymer Solution Instead of Water". NEC Inst. of Eng. and Shipbuilders, **81,** 201 (1965).

[37] Dove, H. L. "The Effect on Resistance of Polymer Additives Injected into the Boundary Layer of a Frigate Model". Proc. 11th ITTC, Tokyo, 1966.

[38] Barnaby, K. C. "A Towing Tank Storm". RINA **107,** 256 (1965).

[39] Kowalski, T. "Turbulence Suppression and Viscous Drag Reduction by Non-Newtonian Additives". RINA, **110,** 207 (1968).

[40] Little, R. C. "Displacement of Aqueous Drag Reducing Polymer Solutions". I. and E.C. Fundamentals, **8,** 520 (1969).

[41] Lang, T. G. "Effect of Drag Reduction and Other Improvements on the Design and Performance of Submerged Vehicles". Viscous Drag Reduction, p313. Plenum Press (1969).

[42] *World Sports*, p6, July 1968.

[43] Killen, J. M. and Almo, J. "An Experimental Study of the Effects of Dilute Solutions of Polymer Additives on Boundary Layer Characteristics". Viscous Drag Reduction, p447, Plenum Press (1969).

[44] Tanner, R. A. "Drag Reduction in a Model of Shear-Flow Turbulence". I. and E.C. Fundamentals, **7,** 32 (1968).

[45] Hoyt, J. W. and Fabula, A. G. "The Effect of Additives on Fluid Friction". Proc. 5th ONR Symposium on Ship Hydrodynamics Bergen (1964).

[46] Gadd, C. E. "Differences in Normal Stress in Aqueous Solutions of Turbulent Drag Reducing Additives". *Nature*, **212,** 1348 (1966).

[47] Gadd, G. E. and Brennan,, C. "Ageing and Degradation of Dilute Polymer Solutions". *Nature*, **215,** 1368 (1967).

[48] Gadd, G. E. "Reduction of Turbulent Friction in Liquids by Dissolved Additives". *Nature*, **212,** 874 (1966).

[49] Jackley, D. N. "Drag Reducing Fluids in a Free Turbulent Jet". Intern. Shipbuilding Progress, **14,** 158 (1967).

[50] Kozicki, W. and Tiu, C. "Anomalous Wall Effects and Associated Drag Reduction in Turbulent Flow". *Chem. Eng. Sci.*, **23,** 31 (1968).

[51] Lumley, J. L. "The Toms Phenomenon". Applied Mechanics Reviews, **20,** 1139 (1967).

[52] Walsh, M. "Theory of Drag Reduction in Dilute High Polymer Flows". Intern. Shipbuilding Progress, **14,** 134 (1967).

[53] Dove, H. L., Canham, H. J. S., Catchpole, J. P. and Long, R. F. "Trials on H.M.S. *Highburton*. Effect of Ejection of Polyox into the Boundary Layer". AEW Report 11/69; AML Report B 112(W), (1969).

ROYAL NAVY EQUIPMENT EXHIBITION

The Royal Navy Equipment Exhibition will be held in the grounds of the Royal Naval College, Greenwich, between 21st - 25th September, 1971.

One of the largest exhibitions sponsored by the Ministry of Defence, it is being supported by a large number of companies manufacturing the equipment which keeps the Royal Navy in the forefront of modern technology. The exhibition will include examples of the latest equipment in use, or about to be introduced into the Navy, covering the full range of mechanical, electrical and electronic ship fitted items.

The exhibition, which will be opened by Vice-Admiral Sir Anthony Griffin, K.C.B., Controller of the Navy, will be restricted to specially invited persons from home and overseas on Tuesday 21st and Wednesday 22nd September. It will be opened to the public on Thursday 23rd, Friday 24th and Saturday 25th September.

British Radiological Protection Association Symposium on Radiological Protection and Society*

Reported by J. R. A. Lakey, B.Sc., Ph.D., F.Inst.P.
Royal Naval College, Greenwich

Over 240 members of BRPA and 17 visitors from overseas attended the Symposium at Imperial College on March 23rd, 1971. The object was to discuss the views on radiation hazards of the public and the Radiological Protection Specialist. The Symposium was opened on the viewpoint of the specialists by Dr. R. H. Mole of the MRC Radiobiology Research Unit at Harwell and Professor H. J. Evans of the MRC Clinical and Population Cytogenic Unit in Edinburgh. Dr. Mole said that the population dose limit recommended by ICRP was based on a social decision as well as a technical estimate. The dose limit recommended is 0·17 rem per year and is comparable in value with the variation of natural radiation background over the United Kingdom. He suggested that radiation exposures of less magnitude were not significant to the public since no one selected their home specifically in areas of low radiation background. He then discussed the somatic effects of radiation exposure and provided evidence to show that neither the linear dose response nor the assumption of constant risk of somatic effect after radiation exposure are necessarily true. The application of these assumptions can lead to overestimate of radiation hazards to the population. He said that the principal source of artificial radiation exposure to the population was the medical use of radiation and if ionising radiation is harming the population then this must be the principal culprit.

Professor Evans then defined the genetic effect as that concerned with small changes or mutations in genes and chromosomes which do not result in cell death. In a muscle cell these mutations may cause cancer whereas in a sperm or egg cell the effect is heritable. Most of these inherited effects are deleterious since it must be accepted that man has evolved by selection of the best of all mutations possible. He said it is valid to assume that all radiation exposure is mutagenic but the spontaneous mutation rate is high and therefore the expected increase in chromosome mutations in offspring of parents exposed to the atomic bomb has not been found.

Lord Richie-Calder based his talk on the surmise that radiation is unsafe at any dose, a concept which was later criticised as implying an aim which might be feasible. Lord Richie-Calder said that he had to emphasise modern man's reaction to nuclear risk which he thought originated from the proclamation of atomic energy to the world as death and destruction in the atomic bomb. He agreed that the nuclear industry was amongst the safest of all industries and set an example to others but he felt that a credibility gap existed between the scientist and the public.

Mr. R. Howells of Hendon College of Technology said that legal men had given radiation unique treatment in the 1965 Nuclear Installations Act because the occupier of a nuclear site is required to accept absolute liability for the consequences of nuclear accidents. The Factory Acts and other laws generally require the employer to do everything practicable to safe-

*Sponsored by the Society for Radiation Protection.

guard his workers but fault must be proved before the occupier is liable for damages.

Mr. Donald Gould, Medical Correspondent of the *New Statesman* reported that intelligent friends whom he had consulted did not give radiation hazards a unique position in their minds. He discovered that they were not worried about the environmental effects of the peaceful uses of atomic energy nor did they contemplate that atomic weapons would be used. Their major concern was the failure of radiation protection experts to dispense information in an acceptable form to the public.

Professor Bo Lindell of the National Institute of Radiation Protection, Stockholm, tried to analyse the attitude of radiation protection experts by assessing their expenditure on radiation protection. He found that the average expenditure in radiation laboratories was 500 dollars to achieve a dose reduction of one man-rad; most laboratories spent between 200 and 2,000 dollars per man-rad. Using a linear dose effect model he contrasted the expenditure on dose reduction by one man-rad against the risk of cancer caused by this radiation exposure. He deduced that radiation protection experts were prepared to spend at least one million dollars to save a human life.

Mr. Craig Sinclair of the Science Policy Research Unit at University of Sussex had studied conventional industries from the same point of view. However, he arrived at their valuation of human life by assuming that the industries had established their expenditure on accident prevention at the optimum. Thus he was able to contrast the observed death rate in the industry with the expenditure to prevent this event. He found that the agriculture industry appeared to value the saving of life at £2,000 whereas the pharmaceutical industry expenditure on safety indicated a value of 30 times this figure.

In spite of the general conclusion that the nuclear industry is well ahead of others in its industrial safety practice, it was generally agreed at the Symposium that there should be no pressure to reduce this expenditure. It was agreed that radiation protection experts must attempt to educate the public to create an attitude on radiation hazards which is developed from a balance between benefit and risk. The Society for Radiation Protection has shown that they are well aware of this need not only by organising this Symposium, but also by the public lecture service which they now offer.

The **Services Electronics Research Laboratory** has for many years been at the forefront of research on a number of semiconductor devices. On May 19th one aspect of this work was displayed at a Conversazione at the Royal Festival Hall, held to commemorate the centenary of the Institute of Electrical Engineers.

The exhibit shown has arisen from research on semiconductor devices which emit light when a current is passed through them. Unlike the widely known filament lamp, semiconductor lamps operate best when cold. They are very reliable, small in size and have a low power requirement.

In one application an array of lamps, less than half an inch high, can be used to display numbers or letters. Where data needs to be presented in a form which is easy to read and can be readily changed, semiconductor lamps are particularly well suited.

The Conversazione was attended by Her Majesty the Queen, accompanied by Prince Philip.

Dr. Colin Gooch is shown with Her Majesty and Prince Philip at the SERL stand.

SIR GEORGE DEACON, K.B., C.B.E., D.Sc., F.R.S. Director N.I.O. Retires

Like many others, **G. E. R. Deacon** joined the Royal Naval Scientific Service in 1939, serving in H.M.S. *Osprey* and H.M. Antisubmarine Establishment until 1944.

He came to the Service with one scientific reputation already made after 12 years in the Discovery Investigations, 12 years which included four long voyages to study the temperature and salinity structure of the Southern Ocean. In ships which lacked much of the gear which modern oceanograprers take for granted there was usually discomfort and often danger. But the precision chemical determinations made are still the basis of our knowledge of the anatomy of the oceans of the Southern Hemisphere. He was awarded the D.Sc. degree for this work and elected a Fellow of the Royal Society in 1944.

By then the Admiralty had begun to realise how little was known of sea-waves. Dr. Deacon was put in charge of Group W (for Waves) at the Admiralty Research Laboratory; in only a year or two they had revitalised the subject by using the then novel method of spectral analysis to interpret instrumental records of sea and swell. Wave research has never looked back.

A major step towards ensuring the post-war development of U.K. Marine Science was taken in 1949 with the formation of the National Institute of Oceanography. Dr. Deacon played a leading part in forming it, from a combination of the physicists of Group W and of the biologists of the Discovery Investigations. It was funded jointly by the Admiralty and the Development Commission until 1965 when it became a component body of the Natural Environment Research Council. Dr. Deacon was the Institute's Director from the outset: at first scattered in various establishments around London the Institute moved in 1953 to its own premises.

Soon the NIO had acquired an international reputation, not only in wave studies and marine biology but also in ocean circulation, in marine geology and geophysics and indeed in almost all the aspects of modern oceanography.

Assiduous in promoting the interests of his own Institute, Dr. Deacon nevertheless had a deep feeling for the multi-national nature of marine science. He travelled widely, supported joint cruises and was prominent in many of the committees set up with the aim of developing international co-operation. His wise counsel is still appreciated at meetings of the Scientific Committee on Oceanic Research and of the International Association for the Physical Sciences of the Ocean, of which he was President from 1960 to 1963.

The continued development of the NIO coincided with a surge of interest in marine science all over the world and Dr. Deacon's part in stimulating it was recognised by the award of many honours and medals. To the Polar Medal awarded early in his career were added the Agassiz Gold Medal of the U.S. National Academy of Sciences, the Albert I Medal of Monaco, the Institute of Navigation Bronze Medal, and latterly a much-prized Royal Medal of the Royal Society and Founders Medal of the Royal Geographical Society. Honorary degrees and Fellowships of Societies and Academies were conferred upon him: he was created C.B.E. in 1954 and K.B. in January 1971.

Sir George retires from his post as Director of the National Institute of Oceanography in July 1971 but hopes to continue his work there and is planning to join a U.S. Research Vessel on a cruise to the Antarctic at the end of the year. His colleagues wish him well.

J. CRONEY, Ph.D., B.Sc. (Eng.)

Dr. J. Croney who is now consultant to the Head of Antenna Research at the Admiralty Surface Weapons Establishment graduated from London University with First Class Honours in Electrical Engineering, and before the war was on the staff of the Northampton Polytechnic, London, now the City University. In 1939 he joined the Eastney Branch of H.M. Signal School, to work under H. E. Hogben, on the early developments of radar receivers at wavelengths of three metres and 50 cms. In late 1940 he was one of a team of four attached to Telecommunications Research Establishment, Swanage (now Radar Research Establishment Malvern) to build a 10 cm radar along lines being pioneered at Swanage. They returned in early 1941 with a breadboard model from which the first Naval 10 cm Radar (Type 271) was developed in the Eastney Laboratories, and fitted in H.M.S. *Orchis* within about six months. The detection of small surface targets at this wavelength was then a remarkable advance.

He continued to work on radar receivers for the rest of the war, developing linear Automatic Gain Control circuits for gunnery radars, and the first sea-clutter rejection circuits. After the war he patented the first noise limiting successive detection logarithmic amplifiers, which were applied to Types 901, 992, and 984 radars.

In 1950 he became head of the Civil Navigational Aids Division of Admiralty Surface Weapons Establishment at a time of rapid development of the Decca Hyperbolic Navigation System. He was personally involved in work on the prediction of errors at Land-Sea boundaries with this system and separately on research into Frequency Modulated radar for close range navigation.

In 1954 he became head of the Antenna Techniques Division in Admiralty Surface Weapons Establishment being promoted to SPSO in 1956; this was before the existence of specific SPSO posts in establishments. At Funtington he conducted personal research work on side-lobe suppression systems, clutter decorrelation techniques by rapid scan antennas, and electronic scanning antennas.

Dr. Croney is the author of many published papers, four of which have received awards from the I.E.R.E. as follows: The Marconi Award 1964 (jointly with P. R. Wallis) for a paper on Side-lobe Suppression Techniques; The Brabazon Award 1966 for a paper on Improved Radar Detection by Clutter Decorrelation; The Institutions highest award. The Clerk Maxwell (1966 jointly with A. Woroncow) for a paper on A True i.f. Logarithmic Amplifier; and again The Brabazon Award (1970 jointly with A. Woroncow) for a paper on Polarisation Effects in Clutter Decorrelation. His Ph.D. was awarded by The University of London in 1966 for a thesis on Radar Clutter Reduction Techniques and an individual merit promotion to DCSO was made in 1967 for his contributions to radar technology. He was honoured to be the only contributor from outside the U.S. to the 1970 McGraw Hill Handbook of Radar (Editor Dr. Skolnik) for which he wrote the chapter on Marine Radar. In 1970 Dr. Croney became visiting Professor of Electronics at the University of Southampton.

NOTES AND NEWS

Admiralty Engineering Laboratory

Mr. D. H. Collins, CO, attended by invitation the Comite International de Thermothynamique et de Cinetique Electrochimiques Section 6—Batteries meeting held at the University of Louis Pasteur, Strasbourg, 26 - 28 April. Attendance was limited to 100 delegates, representing 14 nations, and included seven representatives from the U.K. The theme of the three-day meeting was experimental methods in battery research.

Admiralty Experiment Works

In the early part of this year the installation of a small Circulating Water Channel was completed. The working section is 1·4m wide by 0·84m deep and 5m in length, with a fully adjustable floor to allow shallow water simulation. There is a portable cover plate over the working section, thus providing the facility for running model tests in which both Froude number and cavitation number can be scaled simultaneously if required. The channel will support research into flow conditions over the underwater hull forms.

On May 5th the Defence Scientific Advisory Council visited the Establishment and held discussions with several of the senior officers. At the end of May the Superintendent, Mr. A. J. Vosper visited Gothenburg, Sweden to attend a meeting of the International Towing Tank Conference Executive Committee of which he is a member.

On June 2nd Mr. Vosper, accompanied by the Chief Scientist, Mr. J. E. Conolly, SPSO, and Mr. B. O. Wall, Constructor departed on a 10-day visit to North America. They went first to Canada where they visited the Naval Headquarters in Ottawa and the Defence Research Establishment (Atlantic) in Halifax. Then they proceeded to Washington where they spent a few days at the Naval Ship Research and Development Centre and visited the Naval Ship Research and Development Laboratory in Annapolis. They also visited Hydronautics Incorporated before going finally to New York and visiting the Davidson Laboratory at the Stevens Instiutute of Technology in Hoboken, New Jersey.

Admiralty Underwater Weapons Establishment

Bob Morgan entered Admiralty Service as an Electrical Fitter apprentice some 44 years ago, and joined the original sonar R & D establishment H.M.S. *Osprey* at Portland as a draughtsman in the mid 30s. At the beginning of the war he was transferred for a short time to Bath and then shortly afterwards joined A/SEE at Fairlie. On the return of the establishment to Portland in 1946 he was assimilated into the RNSS as an EO. After spending a few years with the service after-sales group he moved back into the Design Division as a design engineer where he specialised, as did his older brother, in the design of electro mechanical equipment, particularly sonar recorders.

He was ever ready and enjoyed this design work to the full and like a number of similarly trained engineers now retired, played no small part in getting sonar on the map.

Bob also spent a very useful period in producing Test Specifications—an important, though, to many, an unpopular job to be asked to do.

In recent years he has spent his time on electric strain cables and their associated glands and plugs and sockets. In this field he has looked after most of the various requirements of the Establishment, and often had to produce solutions at short notice. His experience and expertise will be a distinct loss to us.

Bob has always done his best to help anyone who came along with a problem, and always in his cheerful, friendly manner.

He was presented with an electric fire by Mr. W. K. Grimley (on right of photograph), O.B.E., head of the Sonar Department, on behalf of his colleagues at AUWE.

FUELS AND LUBRICANTS CONFERENCE

The Admiralty Oil Laboratory plays a key role in the regular exchange of information on Naval Fuel and Lubricant problems at the meetings on fuel and lubricants between the Navies of the United States, Canada and the United Kingdom which have taken place since 1951. These meetings are broadly based in that the delegates include Naval officers, Government scientific staff and appropriate industry and university staff invited because of their special knowledge in this field. In Ottawa (May 1967) and Washington (May 1969) the Australian Navy sent observers. This year the Australians were present as full members and New Zealand sent an observer.

The meetings this year took place in London from April 26th to April 30th, 1971. A full agenda covered panel meetings on fuels, steam and gas turbine oils, diesel engine lubricating oils, hydraulic fluids, grease and miscellaneous. The staff of AOL prepared the "Briefs" on each subject, and a number of reports and memoranda circulated or referred to at the meetings. The Superintendent, Mr. R. P. Langston, his deputy, Dr. D. Wyllie and Mr. J. Ritchie, Head of AOL Chemistry Group were delegates and other members of the staff attended appropriate sessions. Mr. L F. Butcher (AOL Advisory Service was secretary of the Diesel Engine Oil Panel and Mr. R. E. Penfold (AOL Engineering Group) of the Hydraulics Panel.

Some topics which aroused great interest were

(a) the general move to the use of distillate fuels and in particular the needs of gas turbines in marine use by the Navies. This included a presentation by a Rolls Royce delegate.

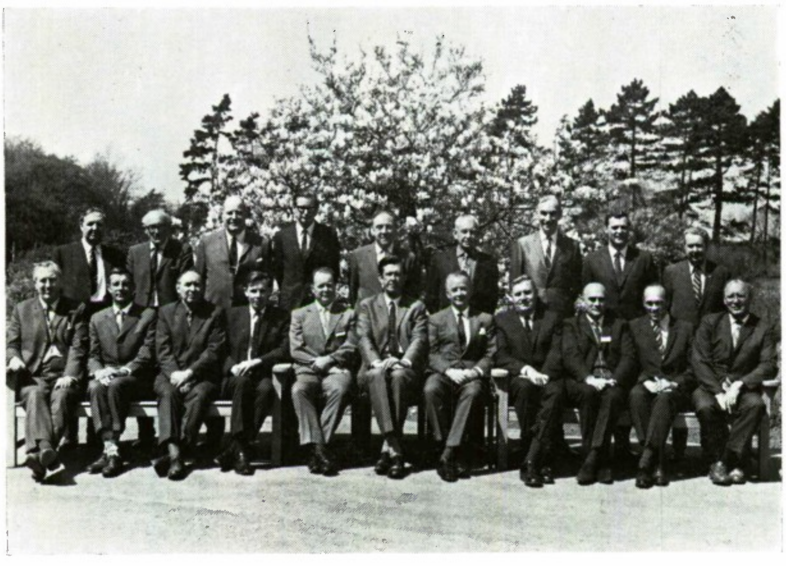
(b) Naval and national interest in pollution and its prevention.

(c) Criteria of safety in storage and use of fuels and lubricants including a presentation by a delegate from Shell on tanker safety.

(d) The general move to higher performance levels for diesel engine lubricating oils in recent years.

(e) The R.N. use of emulsifying oils as hydraulic fluids to control accidental water contamination in submarine hydraulic systems.

Following the meetings in London the Delegates visited the Admiralty Oil Laboratory for two days to finalise the Report, tour the laboratories and final discussions in Closed Session.



Conference members at AOL on Monday 3rd May.

Standing: Mr. W. H. Ray—Head of AOL Engineering Group, Mr. W. E. L. Taylor—Head of AOL Material Characterisation Group. Mr. H. A. Ruffell—Defence Standards Laboratories, Australia, Mr. J. Ritchie—Head of AOL Chemistry Group, Mr. R. G. Grimsey—Canadian Forces Headquarters Project Officer (Canada)IEP/ABCA/3, Dr. R. B. Whyte—Natural Research Council Canada, Mr. A. Macwaters—Canadian Forces Headquarters, Lt. Cdr. A. Morris—Naval Engineering Test Establishment, Montreal, Mr. J. F. Boyle—Naval Ship Engineering Centre (NAVSEC) Philadelphia.

Sitting: Dr. D. Wyllie—Deputy Superintendent AOL, Mr. J. K. Blake—Navy Office, Canberra, Project Officer Australia IEP/ABCA/3, Mr. E. C. Davis—NAVSEC Washington, Mr. M. J. Hodgson—Ship Department MOD(N) Project Officer U.K. IEP/ABCA/3 and Secretary of the Meetings, Capt. T. S. Allan—Canadian Forces Headquarters, Captain P. D. Tatton-Brown—Ship Dept. MOD(N), Mr. T. A. Driscoll—Director of Quality Assurance Australia, Com. J. B. Orem Jr.—NAVSEC Washington, Project Officer U.S.N. IEP/ABCA/3. Mr. R. P. Langston—Superintendent AOL, Dr. G. Bosmajian—NAVSHIPRANDLAB Annapolis and Mr. N. Glassman—NAVSHIPRANDLAB Annapolis.

BOOK REVIEWS

Infrared System Engineering. By Richard D. Hudson, Jr. Pp. xxvi+642; John Wiley & Sons, 1969. Price 185s.

One description of this book would be, unfairly, an annoted bibliography. Certainly the system devised by the author is unusual. The first 15 chapters are a normal, comprehensive and up-to-date treatment of infrared components and systems with an adequate number of references. The last four chapters describe present infrared applications: military, industrial, medical and scientific. This part consists of a large, and probably comprehensive, bibliography with overall summaries and comment in the text, and a short entry on each item. Considering that these four chapters cover nearly 1300 references in this manner this is probably the only way to do the job. The interested reader must then visit his nearest library and start browsing through those aspects of the subject that interest him.

The author describes this book as "the first applications oriented engineering treatment of infrared systems", and later describes a system engineering as requiring a good working knowledge of all the disciplines required to construct the complete system. The coverage of the various topics, such as infrared sources, detectors, noise, etc. fits this description. A specialist in any one of these fields will find nothing new in this book, apart from the system application section, in his own discipline. He will, however, be brought up-to-date as far as military security will allow in the other topics covered.

A previous book published by John Wiley was "Elements of Infrared Technology" by Kruse, McGlaughlin and McQuistan. I have recommended that book on several occasions to colleagues because it gave a comprehensive treatment of the subject when it was published (1962) and in addition it had the rare attribute of always appearing to have the information one required at a particular time in a meaningful form. Only time will tell whether this present book will be as useful. My first impression is that it will not be as good in this respect as the previous book, but it will be adequate for most purposes.

The sytem of units in this book made me a little uneasy, particularly as the table of symbols used did not refer to the defining equation where applicable. Microns instead of micrometres are not too bad, but miles (and occasionally kilo feet) for range requires some careful adjustment of conversion factors. Another example is the formula quoted for the diameter of Airey's disc as $\delta = 0{\cdot}244\ \lambda/D$ which appears to be an order of magnitude in error, until one notices that δ is in milliradians, λ in microns and D in centimetres!

The main omissions arise when a topic is mentioned and is then left after only a paragraph. Cases include Weiner spectra, radiation from objects at nearly the same temperature as the background, atmospheric scintillation, modulation transfer function and the use of F.E.T's in preamplifiers. One statement, that there are no intrinsic detectors beyond 7μ, certainly requires challenging, the mixed crystal Cadmium-Mercury Telluride was even mentioned in the book I referred to earlier, but is omitted completely in this book, as are pyroelectric detectors apart from a mention in a table of detector types.

It is very pleasant to see a reference to the radiation slide rule designed at A.R.L. 20 years ago. A more surprising reference, surely for the first time in an infrared textbook, is one on Guerilla Warfare by M. Tse-Tung, which appears in the systems part of the book.

I would recommend this book to anyone concerned with the design of an infrared system, particularly as in several places some of the pitfalls of simple calculations and blind faith in manufacturers' data are described. I suspect that a specialist in a particular aspect of the overall system would use this book to give him an overall picture rather than a detailed treatment of his own topic. Finally, the last four chapters with their enormous, and fully accessible bibliography of systems is, I believe, unique.

B. R. Holeman

Linear Differential Operators (Part 1). By M. A. Naimark. Pp. 144 + xiii. Published by G. G. Harrap. Price £2.

Naimark has written his work on Linear differential operators in two parts, published separately, and the book under review is the first part subtitled the elementary theory of such operators. In fact, the mathematical techniques used in the first part (from the theory of the complex variable) are essentially not difficult, with, perhaps, the exception of the third (and last) chapter of the book.

The book was first published in 1954 in Russian and has subsequently been translated into German, and now English; the latter edition being influenced and modified somewhat by comments on the German edition. The translation of the preface to the original edition (1954) is interesting in its emphasis of the role played by Soviet mathematicians in the post war development of the subject. It also stresses that up until 1954 no book had been written about higher order differential operators other than the second so well covered by Titchmarch in 1946: these Naimark's book treats extensively.

Naimark's 1968 edition of Part 1 is an excellent introduction to the subject in English, written clearly and not divorced from practical applications—in conformity with the aims expressed in the preface. There are however, only two physical applications and the book is essentially a mathematical text.

The book consists of three chapters, the first of which is devoted to fundamental concepts and basic theorems. It opens with a general abstract definition of a vector space and a linear operator, then introduces nth order linear differential expressions with coefficients defined in an interval and with nth order continuous deviates. By introducing boundary conditions one is led to the concept of a linear differential operator. Self adjoint differential operators, boundary value problems, and adjoint operators are introduced before treatment of the fundamental concepts of eigen values and eigen functions. The general concept of an inverse operator is next introduced and applied to the subject through the use of Green's functions.

The second chapter is devoted to the main problem of the subject, the expansion of an arbitrary function (suitably restricted) in terms of the eigen functions of a linear differential operator. This is preceded by a discussion of the asymptotic behaviour of eigen values and eigen functions for large values of $|\lambda|$ with interesting results. In this chapter further types of boundary conditions are introduced viz. regular and separable.

The last chapter, which is somewhat more difficult than the rest, covers the whole subject again but for vector functions and is equivalent to a set of simultaneous differential operators. This chapter the author claims to be one that discusses topics little treated by other authors.

The book ends with a biblography of 123 references compiled by the translator and covering the period up to 1965. This is intended to serve for both parts of the book and is fairly exhaustive.

While some of the motivation that spurred the author to write his book in 1954 may no longer be true it is still excellent reading for its generality, its clarity and for some of its contents which are probably not adequately treated in any other textbook. It is also very reasonably priced.

R. A. M. Bound

Some Exercises in Pure Mathematics with Expository Comments. By J. D. Weston and H. J. Godwin. Pp. viii + 136. London; Cambridge University Press. Price 65p.

The title of this volume is misleading in that it is not just a collection of mathematical exercises, with notes, for any one section of the student population. Admittedly it does contain two hundred exercises with solutions to some, hints on others and comments on all of them. True too the exercises are on problems forming an alternative syllabus for examinations for students in transition from school to university. However, a note on the back cover says this book is "about some ideas of mathematics" and the authors, teachers themselves, have set out to use the vehicle of problems and solutions to produce a reference book and a framework of systematic study at one and the same time.

Calculus presented as an inductive science has for a long time hindered rather than helped the student and this effect is more and more noticeable with the advent of axiomatic discipline in early mathematical teaching. In their book the authors have provided an alternative and proper approach to analysis in pure mathematics and have very successfully achieved their aims.

D. P. Valler

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